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IMAGE PROCESSING SOFTWARE CONVERSION, VOL I

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RADC-TR-77-51, Volume I (of two)
Final Technical Report
February 1977

IMAGE PROCESSING SOFTWARE CONVERSION
User's Manual and Technical Report

Pattern Analysis and Recognition Corporation

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This report has been reviewed by the RADC Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public including foreign nations.

This report has been reviewed and is approved for publication.

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Interactive, on-line image processing has experienced an expanding interest in many areas of application. As a result, a number of systems based on this approach have been developed in recent years. A pioneer in this area has been the image processing system at RADC which has evolved into a very powerful and comprehensive system. This system came about as a result of separate but co-ordinated efforts in related areas of image processing. Due to a continuing

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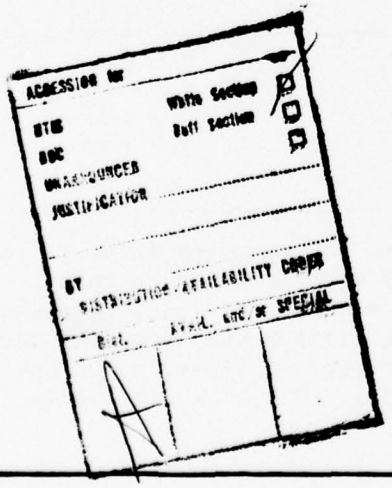
requirement for its capabilities, it is currently being updated to execute on a more recent and powerful processor.

This document is the final report describing the effort by Pattern Analysis and Recognition (PAR) Corporation to convert a portion of the RADC image processing software to allow execution on a DEC PDP 11/45 processor. A section of this report is written in the form of a user's manual for personnel engaged in the operation of the converted software. A companion document contains the detailed system design, the individual program descriptions, and a programmer's manual which describes how new options may be written and incorporated into the system.



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EVALUATION

This effort will greatly increase the Center's capability to digitally process imagery and perform complex analysis of the data in an interactive mode. This volume will allow any user to use the equipment and software to analyze his specific problem. This effort will enable the Center to conduct much-needed research to contribute to future planned digital equipment developments under TPO-1.

David J. Brazil

DAVID J. BRAZIL Capt USAF
Project Engineer

SECTION 1

INTRODUCTION

1.1. INTRODUCTORY REMARKS

Interactive, on-line image processing has experienced an expanding interest in many areas of application. As a result, a number of systems based on this approach have been developed in recent years. A pioneer in this area has been the image processing system at RADC which has evolved into a very powerful and comprehensive system. This system came about as a result of separate but coordinated efforts in related areas of image processing. Due to a continuing requirement for its capabilities, it is currently being updated to execute on a more recent and powerful central processor.

This document is the final report describing the effort by Pattern Analysis and Recognition (PAR) Corporation to convert a portion of the RADC image processing software to allow execution on a DEC PDP 11/45 processor. A section of this report is written in the form of a user's manual for personnel engaged in the operation of the converted software. A companion document contains the detailed system design, the individual program descriptions, and a programmer's manual which describes how new options may be written and incorporated into the system.

1.2. PROJECT BACKGROUND

As previously mentioned, the RADC image processing system was developed through several efforts. As a result, it has been known by a variety of acronyms each of which are descriptive of the contribution made by its related effort to the total system. These acronyms are IFES and DICIFER (Contract No. F30602-72-C-0140), SCORE (Contract No. F30602-72-C-0521) and AMIDS (Contract No. F30602-73-C-0371). Although developed under separate efforts, it exists as one complete software system.

The hardware around which this software system is implemented consists of a DEC PDP 11/20 processor with a variety of peripherals. When development began on the software package, this processor was relatively new. Its capabilities were deemed fully sufficient for the system envisioned. The unforeseen addition of the pattern analysis and recognition algorithms under the AMIDS effort has since rendered this conclusion invalid. The requirement for floating point operations has overloaded the 11/20 which does not support such operations with hardware. Also, DEC has dropped the 11/20 and the RP02 disk from its product line. Both of these are central to the image processing system hardware configuration. As a result, utilization of the software package by other government agencies is limited to those that already have such hardware.

The software package was developed with its own independent operating system. This decision was made due to the unavailability of sufficiently powerful operating systems to support the image processing requirements. Unfortunately, this choice led to a further restriction in the hardware systems upon which it would operate. The resources were necessarily concentrated on developing a wide variety of options at the expense of a general operating system. As a result, it is limited to a very specific hardware configuration.

1.3. SPECIFIC ACCOMPLISHMENTS

Under the current effort, the task of updating the image processing software to a more current and powerful processor was begun. The preprocessing section and a portion of the logic creation section were converted to execute on a DEC PDP 11/45 computer with floating point processor. The independent operating system was dropped in favor of DEC's Disk Operating System (DOS). This provides a more flexible system in terms of the types of disks supported and also the number of disks allowed in the configuration. The software was improved in some instances with respect to its capability and its interaction with the user. These improvements were made on the basis of the considerable experience gained through the use of the system on a variety of application efforts.

Two new options were added and a third option was written to replace a previously existing one. The new system now includes the capability to add a constant to every point in an image and to apply a user designed transfer function to an image. The Hadamard filter option was replaced with a more general routine which allows a weighting matrix to be generated in lieu of a simple binary masking array.

The file system was expanded to allow descriptive information to be stored with each file. This information is provided to the user in an expanded file-directory option.

A centralized error logging scheme was also developed to provide a more informative and consistant error-reporting procedure.

1.4. SUMMARY

Under this effort, PAR has converted a portion of the RADC image processing system to operate on a PDP 11/45. In this conversion process, many significant system improvements were incorporated into both the individual options and the overall system capability. The converted software is also no longer dependent on a particular disk peripheral. Any disk supported by DOS that is of sufficient size for image processing can be used. In fact, the capability has been incorporated to allow files to be created on and retrieved from several disks during any one processing session.

PAR is confident that a major improvement in the image processing system has been realized by this effort. The routines that have been converted are easier to use and are more powerful. To effectively utilize this newly-converted software in future application efforts, it is necessary that the remainder of the system software be converted at an early date. The result will be a modern comprehensive image processing system which can be readily expanded to meet future requirements.

SECTION 2

SYSTEM OVERVIEW

2.1. SYSTEM PHILOSOPHY

The initial effort in the development of the original image processing system addressed the problem of extracting features from reconnaissance imagery based upon spatial characteristics of objects. These features would then be processed on a totally separate system. That system already existed at RADC and was called the On-Line Pattern Analysis and Recognition System (OLPARS). OLPARS consists of a software implementation of several classical pattern analysis and logic creation algorithms. Therefore, the sole original purpose of the image processing system was to extract features and form feature vectors.

As part of the feature extraction process, certain preprocessing operations are sometimes desirable. Therefore, the original effort included a large set of preprocessing routines which generally perform point or neighborhood operations on an image to produce a second image. The capability to combine two images in various ways to form a third image was also included.

The efforts which followed had the effect of broadening the scope of the type of problems that could be attacked on the system. The capability was added to allow sets of images to be processed for the purpose of extracting features based on a point-by-point spectral response. It was also realized that the structure analysis and logic design function must reside on the same system with the feature extraction routines to provide a truly effective interactive system.

As a result of the various goals of the efforts involved, a very comprehensive image processing system has evolved. Its functional capabilities have been applied in numerous application efforts to varying degrees. Some applications require only preprocessing functions to be performed while others require all of the system's capabilities.

All through the system development, the interactive aspect has been emphasized. To be most effective, the human must be involved in every step of the problem solution. To this end, the system presents itself to the user in a modular manner. Each basic function exists as a separate selectable option which must be specifically initiated by user action. Through these option selections, the user builds the solution to his problem in a step-by-step manner. Although this process can be quite long, the most effective solution is obtained. This is realized by the fact that the user must specify the individual processes involved and the parameters to be used for each process. By manipulating these parameters and sometimes the processes involved, each individual step in the problem solution can be optimized.

The modular construction also lends itself to a broader range of applications. By applying the options in various combinations many different goals can be achieved. These goals may range from a simple image enhancement to a full object recognition task.

This general system philosophy has proven effective in many applications. Therefore, it has been retained in the newly converted portions of the image processing system.

2.2. CONVERTED SOFTWARE

Only certain portions of the complete system were selected for conversion under the current effort. These selections were made on the basis of the most frequently used routines. Therefore, a large part of the effort concentrated on the preprocessing section in which most of the routines were converted. In addition, three new routines were written to expand the preprocessing capabilities. These routines allow a constant to be added to all points in an image, an arbitrary transfer function to be applied to an image and a much more complex Hadamard filter to be generated. Details of these and all other converted preprocessing routines are presented in Section 3.

Selected options were also included from the areas of feature extraction and logic creation. The routines to create a set of feature vectors from a spectral set of images and to create Fisher Pairwise or Boolean logics on these vectors were converted. One other routine was included from this area which allows a thematic map to be created from vectors classified by a complete set of logic. This provides a means of visually evaluating the effectiveness of the logic.

The general support routines that allow such things as file deletion and renaming, and directories to be listed were also converted. A new routine was added in this area to allow an image to be entered from the keyboard on a point-by-point basis. Although not thought to be useful for solving practical problems, it is very useful for verifying the performance of newly added options. Therefore, it falls into the category of a program development aid.

Other converted software includes such routines as the binary display routine, the line printer image listing routine and background software such as the executive control program and file system. However, in the latter case, new routines were generated due to the fact that the system was implemented under DOS as opposed to the independent operating system that previously existed.

2.3. USER/SYSTEM INTERACTION

The method of communication between the user and the system that existed previously was retained in the current conversion. The options available to the user are grouped according to function and each of these

groups is then presented as a list on a graphics display. Each such list is called a frame. These frames are numbered consecutively beginning with zero. Frame zero contains no executable routines in its list. Instead, it is a directory of all other frames in the system. Selection of any option in this frame causes the corresponding frame to be displayed.

Frames other than frame zero contain options that, when selected, initiate the execution of a routine. Each such routine queries the user to obtain required information such as input and output file names and execution parameters and options.

2.4. HARDWARE REQUIREMENTS

The converted software has less stringent hardware requirements than the previous system. The processor must be a PDP 11/45 computer with floating point hardware. The system is currently configured to execute under DOS in 28K words of core. This core requirement can be reduced through a simple modification of the software. However, execution time on some routines would increase tremendously, so it is therefore not recommended.

At least one disk must be present in the system. The smallest disk on which any processing can be accomplished is an RK05. In this case, it is highly recommended that at least two disk drives of this type be available to provide sufficient storage for data files. A much better configuration would contain one RK05 for DOS and system software, and a larger disk such as an RP03 for data file storage. A second RP03 drive would be convenient to allow file transfers from one disk pack to another. This greatly reduces the time required to generate and maintain data bases. In any case, it should be noted that the software can execute on a variety of disk peripherals. In fact, data files can be accessed from multiple disks simultaneously. This is a significant improvement over the old system which could only access data files from a single disk, and that disk necessarily had to be an RP02.

The system is currently designed to interact with the user through a Tektronix 4000 series graphics terminal. Although modifications could be made to utilize other terminals, such a task would not be straightforward. Certain displays presented contain a high information density, and therefore require a storage type of display. Any attempt to present them on a refresh display would result in very serious flicker problems.

A line printer is required by certain routines for directories, image file listings and thematic map summaries. Also, routines exist for industry-compatible tape I/O. Therefore, such peripherals should exist in the system. The line printer is expected to be a 132-column printer.

An image display is not currently supported by the software, although it can be added easily (see the accompanying programmer's manual). Existing hardware installations have different displays and therefore it is left to each individual user agency to provide its own display software. Experience has shown that display options are the most exercised in the system and should therefore be very flexible, fast and efficient. As a result, considerable thought must precede its development.

The converted software currently provides for only one method of data input which is via magnetic tape. A scanning device for direct image input is not included in the configuration. Again, however, access to such peripherals can easily be added to the software system by the user agency.

SECTION 3

SYSTEM OPERATION

This section is prepared in the form of a user's manual for personnel engaged in the operation of the image processing system. The first portion discusses the general system characteristics and the conventions for user interaction. This is followed by the step-by-step system start-up procedure and the individual option descriptions.

3.1. SYSTEM CONVENTIONS

3.1.1. Keyboard Entries

The graphics display keyboard and its associated cursor are the only means of communication with the system. As entries are requested on the display, the user types his response at the keyboard. These entries are not accepted by the system until a terminating carriage return is typed. Errors may be corrected prior to the entry of the carriage return in one of two ways. Individual characters may be deleted by striking the rubout key. Each time that this key is struck, the last character in the string is deleted. As the characters are deleted, they are printed on the display. To separate them from the text, initial and terminating backslashes are printed.

A second method of correction is to delete the entire string and begin anew. This is accomplished by striking the "U" key while holding down the "CNTL" key. The entry can then be retyped on the next line.

3.1.2. Frame Displays and Interaction

Since the number of options in the system is too large to present to the user at any one time, they have been grouped according to function. Each group is presented on the graphics display as a list of numbered options. These lists are called frames and are each assigned a number.

Upon entering the system, the first frame presented is Frame 0. This frame simply contains a list of all other frames in the system and can therefore be thought of as a directory. To display any of the other frames, the user simply enters its associated option number at the keyboard followed by a carriage return. This causes the display to be cleared and the new frame to be presented. In all frames, the user may make option selections whenever the prompting character "#" is printed by the system.

In each of the other frames, the options consist of executable programs except for two exceptions in each frame (one exception in Frame 12). Each frame has one option which when selected causes Frame 0 to be redisplayed. In this manner the user can then select any other frame in the system. The second exception consists of an option that when selected causes Frame 12 to

be displayed. This option is included because the display functions in Frame 12 are frequently used.

A second method of transferring from frame to frame is included which may be more convenient for the experienced user. This type of transfer can be effected at any time that the system is waiting for a frame option selection. The form of the entry is the frame number preceeded by the letter "F". Therefore, to transfer to Frame 10, the entry would be

F10

followed by a carriage return.

The executable options are selected in the same manner that the frame transfer options are selected. That is, the desired option number is entered with a terminating carriage return. Following selection, the program specified by the option is executed. Any file names or parameters required by the program are then requested. The user responds to these requests by typing the entries as specified by the program query. Upon completion of its task, the program exits and another frame option can then be selected.

Execution of a routine can be discontinued at any time by striking the "C" key while holding down the "CNTL" key. The system then prints a dot. The frame option mode is then re-entered by typing "RE" followed by a carriage return.

Detailed discussions of the frames and their options are presented later in this section. Included in these discussions is the dialogue associated with each routine.

3.1.3. File Specifications

As discussed in the previous section, the system is not restricted to any one particular disk for data file storage and retrieval. A concept of a default device and unit number has been incorporated into the system. This means that unless otherwise specified, file I/O will be performed on a preselected disk type and unit number. These defaults can be specified in one of two ways. The first method involves modifying the system-building batch stream and rebuilding the system (see the programmer's manual). The second is simply done at the keyboard at execution time. The main difference is that the first method results in a permanent change, whereas the second method is effective only for that session on the system.

A method also exists for overriding the default device and unit for any given file. This capability was provided by adopting the file-naming convention of DOS. Under this convention, the complete description of a file with respect to its name, type and location is called the file specification. It is given in the following format:

Dev:Filename.Extension

where "Dev" is the device mnemonic and unit number, "Filename" is the six-character name of the file and "Extension" is the three-character filename extension which indicates the type of file. The device mnemonics are the same as those defined under DOS. The unit number is a single numeric which indicates the number of the particular device unit. For example, an image file located on unit one of an RK05 disk under the name "FILEAA" would be specified as:

DK1:FILEAA.IMG

The extension "IMG" indicates that the file is an image file (see Appendix A for a complete list of file types). If the above specification is entered as,

FILEAA.IMG

then the default device and unit number would be assumed. It should be noted that the file name itself may consist of from one to six characters where the first character must be a letter.

Most routines in the system demand a particular file type for input and output. Therefore, the file name extension need not be entered. In fact, if it is entered, it is ignored. Those routines that do require an extension to be entered specifically request it with the file name.

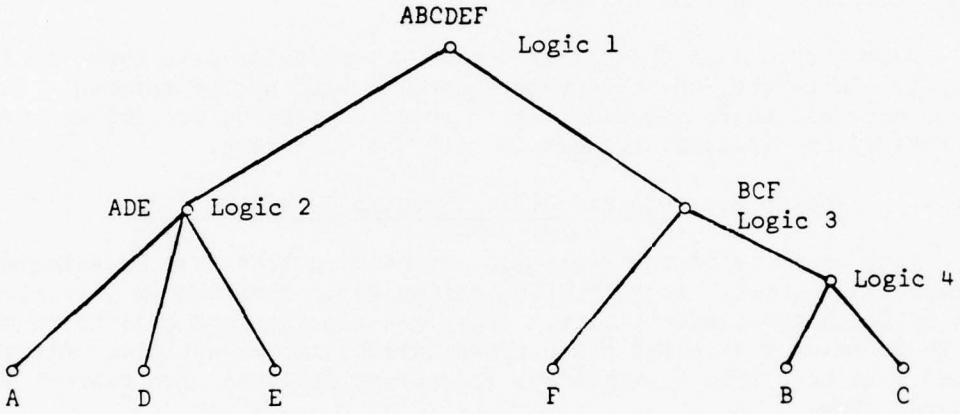
3.1.4. Vector Analysis and Logic Creation Considerations

Most routines in the system do not require that they be selected in a prespecified order. In fact, the ability to be combined in any order gives the system a great flexibility. The logic creation and related routines, which do have an expected order of selection, are exceptions. Although their order does have some flexibility, it must be followed with respect to its general flow.

To create logic one must first have a set of feature vectors on which to design the logic. Currently, a spectral set of images is the only source for measurement vectors. A spectral set consists of two or more image files each of which covers the same scene but in a different part of the electromagnetic spectrum. The members of the spectral set are listed by name and the device upon which they reside in another file called a "spectral set" file. Since vectors may be created on the basis of each point within specified regions of the spectral set, the spectral set file also contains a list of names of region files and the devices upon which they reside. Along with each region, a class symbol is included which is used to identify the vectors that are formed from the points within the region. A data reduction factor is also included for each region to allow a subset of the points within the region to be used for forming vectors. Thus, the spectral set file completely describes the spectral set and the manner in which vectors are to be formed from it. This insures consistency when measurements are added to a vector file that was previously created from the spectral set.

In the adopted scheme there is a one-to-one correspondence between a spectral file set and a vector file. Since it is frequently desirable to create logic on vectors from several spectral sets, a mechanism is included to specify a set of vector files. This is also done by listing the names of the vector files and the devices upon which they reside in another file called a "vector set" file. All references to vectors by the logic creation routines are then made through this file. All vectors in the set are included in the logic creation and evaluation operations.

Logic is constructed in a tree format where a different type of logic may be used at each node in the tree. The overall goal is to create a logic for each node such that the group of classes entering at the senior node or root of the tree is passed through the tree so that one and only one class of vectors ends up at each lowest node or terminal branch of the tree. This can be pictorially represented as follows:



Since several logics may be created in building a given tree for a given vector set, a current vector set and logic tree concept is incorporated. Therefore, before logic can be created, a vector set and a logic tree must be selected. These are then "remembered" by the system for all future operations during that session. This information is not retained after system shut-down and must be re-entered at the beginning of the next session.

3.1.5. User Designed Programs

An option exists in Frame 11 to allow newly written routines to be tested and executed without permanent incorporation into the system frames. After the routine is functioning properly and if it is found to be useful, it may then be included as a permanent option entry. The procedures for writing routines and adding them to the system are discussed in the associated programmer's manual.

3.1.6. Error Reporting

Errors are indicated by printed messages on the keyboard display. Two classes of errors exist in the system. The first class is recoverable and is indicated by the characters "E0" preceding the message. Such errors result from incorrect entries made by the user. The remedial action is included in the message which in most cases is to simply try again.

The second class of errors indicated by the characters "E1" preceding the message is fatal. These errors are reported when no recovery is possible. In such cases the routine is aborted and the user may then select a new frame option.

A complete list of the possible error messages and their explanations is provided in Appendix B.

3.1.7. Recording the User/System Dialogue

An option exists in Frame 13 to allow a log of operations to be recorded for future reference. This log is stored on the default device and may be listed on the line printer upon command. It should be noted that this file will be lost if the user exits the system via the DOS "KILL" command. For this reason, that command is not detailed here and should be avoided. An exit from the system should be taken via the DOS option in Frame 13 or as explained in the next paragraph.

3.1.8. Miscellaneous Functions

Two other functions are provided by the image processing executive that are not presented to the user as numbered options. First, an exit from the system can and should be made by typing the characters "DOS" at any time that the system is prompting with the character "#". The DOS "KILL" command should not be used for this purpose (see paragraph 3.1.7).

A second function can be invoked by typing "CONTINUE" or simply "CO" in response to the "#" prompt. This command puts the executive to sleep and all ensuing input is recognized only by the log routine. This allows the user to enter comments into the log for future reference. To awaken the executive, the user need only enter a carriage return as the first character of a new line. The system then once again prompts with the "#".

3.2. SYSTEM START-UP PROCEDURE

It is assumed that the user is sufficiently familiar with DOS to the point that he is able to load the required disks and boot the monitor into core. After setting the date and time as prescribed by DOS, a user number under which data files are to be stored and retrieved should be entered. A user number consists of two octal numbers separated by a comma. Numbers less than 11 should not be used. Also, [11,11] is reserved for the image processing software and should not be used.

The system is then activated by typing the following command:

```
RU   IPS[11,11]
```

The system software is expected to reside on the DOS system disk under user number [11,11]. The following message then appears:

```
IMAGE PROCESSING SYSTEM V002

DO YOU WISH TO CHANGE DEFAULT PARAMETERS?
```

As explained in 3.1.3, a default device and unit are used for file storage and retrieval when none is specifically entered with a file name. If this default is to be changed, the user should respond with "Y". After a "Y" response, the dialogue proceeds:

```
THE CURRENT DEFAULT DEVICE IS dev:
ENTER NEW DEVICE
```

where dev: is the standard DEC device mnemonic for the current default device. If it is to be changed, the new mnemonic should be entered. Otherwise, a carriage return should be typed. The next query is:

```
THE CURRENT DEFAULT UNIT IS n
ENTER NEW UNIT
```

where n is the current default unit. If this is to be changed, the number corresponding to the desired unit should be entered. If it is not to be changed, a carriage return should be typed.

At this point, or if the user had responded with an "N" to the first query, the first list of options, Frame 0, is presented on the graphics display. This frame contains a list of all other frames within the system. No executable routines are referenced by this frame. At this point, the frame which the user wishes to be displayed may be selected by entering its corresponding option number. The selected frame is then displayed. Routines are then selected for execution by entering their corresponding option numbers from the frame option list. When the execution of the option is complete, another option may be selected or a new frame may be displayed.

The descriptions of the frames and execution dialogues for each executable option are included in the following pages.

3.3. FRAME AND OPTION DESCRIPTIONS

In the remaining portion of this section, the frames and the options contained therein are discussed in detail. Interactive dialogue is included for each executable option.

3.3.1. Frame 0 - Master Frame

This frame is simply a directory of all other frames in the system. Selection of any option causes the corresponding frame to be displayed.

```
FRM 0-MASTER FRAME

 1 - DATA EDITING
 2 - TRANSFER FUNCTIONS
 3 - STATISTICS
 4 - SMOOTH IMAGES
 5 - COMBINE IMAGES
 6 - NOISE REDUCTION
 7 - EDGE DETECTION
 8 - TRANSFORMS
 9 - FEATURE EXTRACTION
10 - LOGIC DESIGN
11 - FILE MANIPULATIONS
12 - DISPLAY OPTIONS
13 - UTILITY FUNCTIONS
```

3.3.2. Frame 1 - Data Editing

This frame contains options which allow the user to create an image file from a subportion of another image, to specify a region within an image, to translate an image or to reduce an image in size by retaining every Nth point. Regions specified within an image are recorded in a region file as coordinate pairs describing their boundaries.

```
FRM 1-DATA EDITING

1 - RECT AREA SELECT
2 - SPECIFY REGION COORDS
3 - SHIFT IMAGE
4 - DECIMATION
5 - DISPLAY OPTIONS
6 - MASTER FRAME
```

RECT AREA SELECT

FRAME 1

General Description:

This routine allows the user to select a rectangular area within an image and to create a new image file consisting of all the points within the rectangular area. This new file is treated independently of the original image with respect to coordinate references; i.e., the top left-hand pixel is in row 1, column 1. The specification of the area is via the keyboard. The user enters the row and column number of the top left-hand corner of the rectangle and the size of the rectangle in rows and columns.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
AREA START ROW =	Enter the number of the first row to be included within the area.
NUMBER OF ROWS =	Enter the number of rows to be included within the area.
AREA START COL =	Enter the number of the first column to be included within the area.
NUMBER OF COLUMNS =	Enter the number of columns to be included within the area.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

SPECIFY REGION COORDS

FRAME 1

General Description:

This routine allows the user to create a region file by entering the coordinates of the region at the keyboard. An option to specify the coordinates via an image display has also been provided. However, the image display software was not included as a part of this effort and therefore this option is inoperative.

The keyboard specification can be done by either of two methods. A rectangular region can be specified by entering the upper left corner coordinates of the region and its size in terms of rows and columns. The second method allows the user to enter each coordinate pair describing the region. The order of the pairs is assumed to trace the boundary (clockwise or counterclockwise) of the region. If the final coordinate pair does not match the first, an additional pair is added to insure a closed boundary.

Dialogue:

System	User Response
OPTIONS: 1 - TYPE EACH COORD 2 - TYPE TOP LEFT AND SIZE 3 - SPECIFY WITH CURSOR 4 - EXIT SELECTION =	Enter the number of the desired option.
	Option 1
ENTER COORDINATES. TERMINATE LIST WITH A CNTRL-Z. ROW, COL =	Enter the row and column values (on one line) describing each coordinate pair in the desired region boundary. Type a "Z" while holding down the "CNTL" key to terminate the list of entries.
The last line above is repeated to allow several coordinates to be entered.	
OUTPUT REGION NAME =	Enter the name to be assigned to the new region file.
The region is created and control returns to the initial option list.	

SPECIFY REGION COORDS (Continued)

Option 2

UPPER LEFT ROW AND COL COORDINATES = Enter the row and column coordinates (on one line) of the upper left corner of the desired region,

ROWS AND COLS IN BOX = Enter the number of rows and columns (on one line) to be included in the region,

OUTPUT REGION NAME = Enter the name to be assigned to the new region file.

The region is created and control returns to the initial option list.

Option 3

Note: This option is currently inoperative.

INPUT IMAGE NAME = Enter the name of the image file to be displayed.

BLOW UP FACTOR = Enter the blow up factor to be used for displaying the image. Positive values expand the image and negative values reduce it. Values of -1, 0 and 1 have no effect.

Normally, the image is displayed at this time. However, currently the following is printed:

OPTION INOPERATIVE!!!

and the routine exits.

SELECT REGION COORDS. WITH CURSOR
TYPE A TO ACCEPT RESULTING REGION
TYPE R TO REJECT AND RESELECT REGION
SELECTION = Select each coordinate in order around the desired boundary. When complete type "A" to accept it or "R" to reject it and try again.

OUTPUT REGION NAME = Enter the name to be assigned to the new region file.

The region is created and control returns to the initial option list.

SPECIFY REGIONS COORDS (Continued) Option 4

The routine exits to the executive to allow a new frame selection to be made.

SHIFT IMAGE

FRAME 1

General Description:

This routine shifts an image upward and to the left by a specified number of rows and columns. The result is stored in a new image file. Rows shifted off the top of the image are inserted at the bottom and columns shifted off the left edge are entered at the right. For example, suppose that an image of 140 rows and 112 columns is to be shifted by 3 rows and 2 columns. The following changes would occur:

```
Row 4 becomes Row 1
Row 5 becomes Row 2
Row 6 becomes Row 3
      .
      .
      .
Row 140 becomes Row 137
Row 1   becomes Row 138
Row 2   becomes Row 139
Row 3   becomes Row 140
```

and,

```
Column 3 becomes Column 1
Column 4 becomes Column 2
      .
      .
      .
Column 112 becomes Column 110
Column 1   becomes Column 111
Column 2   becomes Column 112
```

If a shift down to the right is desired, it can be accomplished by specifying the total number of rows or columns in the image minus the number of rows or columns respectively in the desired shift.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
ROW SHIFT COUNT (UP) =	Enter the number of rows by which the image is to be shifted.
COLUMN SHIFT COUNT (LEFT) =	Enter the number of columns by which the image is to be shifted.

DECIMATION

FRAME 1

General Description:

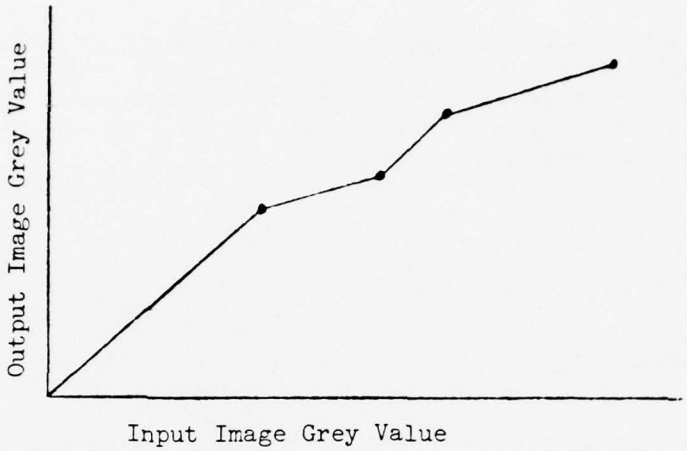
This routine allows the user to reduce the size of an image by discarding data points. This is accomplished by creating a new image that consists of every Nth row and every Mth column of the selected image. For example, if N=2 and M=3, the rows retained would be 1, 3, 5, 7, ..., and the columns retained within each of these rows would be 1, 4, 7, 10, ... The effect of this routine is to reduce the resolution.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
KEEP EVERY NTH ROW AND MTH COLUMN N=	Enter the desired row decimation factor.
M=	Enter the desired column decimation factor.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

3.3.3. Frame 2 - Transfer Functions

This frame contains options that allow transfer functions of various types to be applied to an image. A transfer function can be graphically portrayed as follows:



where the actual function is determined by the selected option. The transfer function is applied on a point-by-point basis. For each input value, the function defines an output value. Since an image can take on values from zero to 255, the function must be defined over this range of input values. The output, however, need not produce values over this entire range.

FRM 2-TRANSFER FUNCTIONS

1 - ADD CONSTANT
2 - THRESHOLD
3 - NORMALIZE
4 - ELEMENT CHANGE
5 - RANGE CHANGE
6 - ARBITRARY FUNCTION
7 - DISPLAY OPTIONS
8 - MASTER FRAME

ADD CONSTANT

FRAME 2

General Description:

This routine allows the user to add a constant (positive or negative) to every pixel within a selected image. Following the addition, values less than zero are made equal to zero and values greater than 255 are made equal to 255. The number of pixels falling into each of these categories is listed for the user's information.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
CONSTANT TO ADD TO IMAGE =	Enter the desired signed constant.
NO. OF PIXELS FORCED TO 255 = n	
NO. OF PIXELS FORCED TO Ø = m	

THRESHOLD

FRAME 2

General Description:

This routine allows the user to change a specified grey value range within an image to any one grey value (0 - 255). Three options are available to the user for accomplishing this. The first option is to simply enter the name of a transfer function file which was generated from a previously entered set of ranges and replacement values. Second, the user may enter the ranges and their replacement values at the keyboard and save them in a new transfer function file for recall. The last option is the same as the second option above except that a new file is not created.

The following is an example of a possible set of ranges and replacement values:

Range	Replacement Value
0 to 50	0
51 to 101	63
102 to 152	127
153 to 203	191
204 to 255	255

The first range entered begins at zero. Each succeeding range must follow in increasing order. If the user does not specify the final range to extend up to 255, then a final range is automatically added which is given a replacement value of 255.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
TRANSFER FUNCTION FILE OPTIONS: 1 - USE OLD FILE 2 - CREATE NEW FILE 3 - NO FILE SELECTION =	Enter one of the three listed options.

Option 1

TRANSFER FUNCTION FILE NAME =

Enter the file name associated with a transfer function which is to be applied to the specified image.

Option 2

TRANSFER FUNCTION FILE NAME =

Enter the file name to be assigned to the transfer function to be created in the following steps.

ENTER HI, NEW DENSITIES
TERMINATE LIST WITH CNTRL - Z
HI, NEW =
(last line repeated until the user terminates input)

Enter the high value defining the desired grey value range and the replacement value for the range separated by a comma. The low value for the first range begins at zero and for each succeeding range begins at the previous high value plus one. The list is terminated when the user responds by typing "Z" while holding down the "CNTL" key and then typing a carriage return.

Option 3

Same as Option 2 except that a transfer function file name is not requested.

NORMALIZE

FRAME 2

General Description:

This routine linearly expands the existing grey value range of an image so that at least one pixel has a grey value of zero and at least one has a value of 255. This can be expressed as follows:

$$O_{ij} = ((I_{ij} - MIN)*255)/(MAX-MIN)$$

where O_{ij} is the pixel at the i^{th} row and j^{th} column in the output image

I_{ij} is the pixel at the i^{th} row and j^{th} column in the input image

MIN is the minimum grey value in the input image

MAX is the maximum grey value in the input image

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

ELEMENT CHANGE

FRAME 2

General Description:

This routine allows the user to change specified grey values within an image to any replacement values (0 - 255). Three options are available to the user for accomplishing this. The first option is to simply enter the name of a transfer function file which was generated from a previously entered set of grey values and replacement values. Second, the user may enter the grey values and their replacement values at the keyboard and save them in a new transfer function file for recall. The last option is the same as the second option above except that a new file is not created.

Only those grey values specified by the user are modified with the replacement values. All other grey values are transferred to the output file unchanged.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
TRANSFER FUNCTION FILE OPTIONS: 1 - USE OLD FILE 2 - CREATE NEW FILE 3 - NO FILE SELECTION =	Enter one of the three listed options.
	Option 1
TRANSFER FUNCTION FILE NAME =	Enter the file name associated with a transfer function which is to be applied to the specified image.
	Option 2
TRANSFER FUNCTION FILE NAME =	Enter the file name assigned to the transfer function to be created in the following steps.

ENTER OLD, NEW DENSITIES
TERMINATE LIST WITH CNTRL-Z
OLD, NEW =
(last line repeated until the user terminates input)

Enter the grey value and its replacement value on one line separated by a comma. No limit is given for the number of grey values specified. The list is terminated when the user responds by typing "Z" while holding down the "CNTL" key and then typing a carriage return.

Option 3

Same as Option 2 except that a transfer function file name is not requested.

RANGE CHANGE

FRAME 2

General Description:

This routine linearly expands a selected range of grey values within an image to the maximum possible range (0 - 255). All grey values below the range are made equal to zero and all grey values above the range are made equal to 255. The low and high limits of the range become zero and 255 respectively.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
LOW, HI DENSITIES =	Enter the lower and upper grey values which define the desired range. Entry is on one line separated by a comma.

ARBITRARY FUNCTION

FRAME 2

General Description

This routine allows the user to generate a piecewise linear transfer function and apply it to an image to create a new output image. A piecewise linear transfer function is one that is constructed of two or more straight line segments. Three options are available. The first option allows a previously entered transfer function to be recalled via its file name for application. The second option allows a new transfer function to be created, saved in a file, and applied to an image. The third option simply allows a new transfer function to be generated and applied to an image.

A new transfer function is entered via the keyboard as a list of coordinates. These coordinates define the end points of each segment of the piecewise linear function. Following entry of this list, the resulting transfer function is graphically displayed for acceptance or rejection. If it is accepted, the user is then given the option to enter a title on the display for hardcopy purposes. Following this, the transfer function is applied to the specified image.

If the user rejects the transfer function, he is then allowed to enter a new list of coordinates and the process repeats.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
TRANSFER FUNCTION FILE OPTIONS: 1 - USE OLD FILE 2 - CREATE NEW FILE 3 - NO FILE SELECTION =	Enter one of the 3 listed options.
	Option 1
TRANSFER FUNCTION FILE NAME	Enter the file name associated with a transfer function which is to be applied to a specified image.

ARBITRARY FUNCTION (Continued)

OPERATION IN PROGRESS
(Transfer function is applied.)

OPERATION COMPLETE

Option 2

TRANSFER FUNCTION FILE NAME =

Enter the file name to be assigned to the transfer function to be created in the following steps.

ENTER TRANSFER FUNCTION COORDS

TERMINATE LIST WITH CNTRL-Z

NOTE:THE X VALUES MUST BE IN INCREASING ORDER

X represents the input image grey value. Y represents the output image grey value. (Ref. pg. 3-15)

(X, Y) =
(last line is repeated until the user terminates input)

Enter the X and Y coordinate values describing the transfer function. One coordinate pair per line which is separated by a comma. The list is terminated when the user responds by typing "Z" while holding down the "CNTL" key and then typing a carriage return.

At this point the transfer function is displayed with the following query:

A=ACCEPT, R=REJECT

Enter an A followed by a carriage return to accept the transfer function or an R followed by a carriage return to reject it. Rejection causes a new list of coordinates to be requested as above. Acceptance continues below.

TITLE:

Enter a title if desired. When a carriage return is entered, either alone or following the title, the display is cleared and the transfer function is applied to the image.

OPERATION IN PROGRESS
(Transfer function is applied.)

OPERATION COMPLETE

Option 3

Same as Option 2 except that a transfer function file name is not requested.

3.3.4. Frame 3 - Statistics

This frame contains options which provide various statistics on a given image, a row within an image or a region within an image. Regions are defined via the options in Frame 2.

```
FRM 3-STATISTICS

1 - IMAGE HISTOGRAMS
2 - REGION HISTOGRAMS
3 - REGION STATISTICS
4 - MULTIREGION STATISTICS
5 - IMAGE ROW INTENSITY PROFILE
6 - DISPLAY OPTIONS
7 - MASTER FRAME
```

IMAGE HISTOGRAMS
and
REGION HISTOGRAMS

FRAME 3

General Description:

These routines display histograms of grey value intensities or point-neighborhood grey value comparisons. The only difference between the two options is the source of data. IMAGE HISTOGRAMS option computes the histograms on the basis of an entire image, whereas the REGION HISTOGRAMS option computes them on the basis of selected regions within an image.

Each option has an identical set of four suboptions for choosing the type of display. All four suboptions display histograms using the same display format and system/user dialogue. The only difference is the method of computing the histogram.

The INTENSITY option computes a histogram consisting of the frequency of occurrence of the grey values within an image or within regions of an image. The histogram consists of 256 bins, one bin for each grey value.

The other three options compute the absolute differences between each pixel and each of its eight neighbors. The MIN.DIFFERENCE option generates the histogram based upon the minimum difference in each set of eight absolute differences. Similarly, the MAX.DIFFERENCE option bases its histogram on the maximum differences, and the AVE.DIFFERENCE option computes the average of the eight absolute differences for its histogram. Since the possible range of these differences is 0 to 255, a 256 bin histogram is also generated.

The initial display for all options consists of the 256 bin histogram. The user is then given several options. The first option allows a portion of the histogram in the horizontal direction to be expanded to full scale. The second option expands the histogram in the vertical and horizontal directions. The vertical expansion causes the maximum bin value within the specified horizontal range to be represented as the full scale value. The third option allows the user to change the number of bins into which the data is grouped. If this number does not result in an integer number of grey values per bin, the largest number satisfying this condition which does not exceed the specified number is used. The fourth option displays a cumulative histogram. Each bin in the cumulative histogram consists of the sum of all bins in the original histogram from the zero bin up to and including the current bin. The fifth option determines the percentage of the total bin counts which lie within a specified range. The sixth option allows the user to change the tick mark spacing along the vertical axis. The seventh and eighth options simply allow the histogram to be displayed as lines connecting the maximum value of each bin or as traditional histogram bars.

IMAGE HISTOGRAMS (Continued)
and
REGION HISTOGRAMS

For each display, the vertical axis range (bin counts) and the range of the plotted data (minimum and maximum bin counts displayed) are listed. The sum of all bin counts over the range, the file name, the current date and time, the number of bins displayed, and the spacing between the vertical axis tick numbers are also displayed.

Dialogue:

System	User Response
OPTIONS: 1 - INTENSITY 2 - MIN. DIFFERENCE 3 - MAX. DIFFERENCE 4 - AVE. DIFFERENCE SELECTION =	Enter the number of the option describing the type of histogram desired.
INPUT IMAGE NAME =	Enter the name associated with the desired image file.
For the REGION HISTOGRAMS option the following query is made:	
INPUT REGION FILE NAME =	Enter the file name associated with a region which is to be included in the computations. Several names can be entered (on separate lines). When all names have been entered, respond to the query with a carriage return alone.
The above is repeated to allow several regions to be specified.	
The histogram is computed and displayed.	

Original Histogram Options

OPTIONS:
1 - ZOOM-X
2 - ZOOM-XY
3 - NO. BINS
4 - CUM. HIST.
5 - PERCENT
6 - NEW TICKS
7 - LINES
8 - BARS
9 - EXIT
SELECTION =

Enter the number of the desired option.

Options 1 & 2

LO, HI =

Enter the lower and upper limits of a range of values to be displayed. Both numbers should be entered on the same line separated by a comma.

A new histogram is displayed and control transfers to the "Zoom Histogram Options" below.

Option 3

NO. BINS =

Enter the number of bins desired in the histogram. The limits are from 2 to 255.

A new histogram is displayed. No change occurs in the option list.

Option 4

The current display is changed to a cumulative histogram. Control transfers to "Cumulative Histogram Options" below.

Option 5

LO, HI =

Enter the lower and upper limits between which the percentage of the total bin counts is to be determined. Both numbers should be entered on the same line separated by a comma.

n%
COUNT = m

(Where n is the percentage and
m is the sum of the bin counts
within the range.)

A new option selection is requested.

Option 6

EACH TICK =

Enter the bin count spacing desired between the vertical axis tick marks (only integer values are allowed).

The new histogram is displayed. No change in the option list.

Option 7

The current display is changed to a line display. No change in the option list.

Option 8

The current display is changed to a bar histogram. No change in the option list.

Option 9

The frame displayed upon entry to this routine is redisplayed and control returns to the executive.

Zoom Histogram Options

OPTIONS:
1 - FULL RANGE
2 - PERCENT
3 - NEW TICKS
4 - LINES
5 - BARS
6 - EXIT
SELECTION =

Enter the number of the desired option.

Zoom Option 1

Return to the display which existed prior to selecting the zoom.

Zoom Option 2

LO, HI =

Enter the lower and upper limits between which the percentage of the total bin counts is to be determined. Both numbers should be entered on the same line separated by a comma.

n%
COUNT = m
(Where n is the percentage and m is the sum of the bin counts within the range.)

A new option selection is requested.

Zoom Option 3

EACH TICK =

Enter the bin count spacing desired between the vertical axis tick marks (only integer values are allowed).

The new histogram is displayed. No change in the option list.

Zoom Option 4

The current display is changed to a line display. No change in the option list.

Zoom Option 5

The current display is changed to a bar histogram. No change in the option list.

Zoom Option 6

The frame displayed upon entry to this routine is redisplayed and control returns to the executive.

Cumulative Histogram Options

OPTIONS:
1 - ORIG. DISP.
2 - ZOOM-X
3 - ZOOM-XY
4 - NO. BINS
5 - NEW TICKS
6 - LINES
7 - BARS
8 - EXIT
SELECTION =

Enter the number of the desired option.

Cumulative Option 1

Control returns to the display which existed prior to selecting CUM. HIST. option.

Cumulative Options 2 & 3

LO, HI =

Enter the lower and upper limits of the desired range of values to be displayed. Both numbers should be entered on the same line separated by a comma.

The new histogram is displayed. Control transfers to the "Cumulative Histogram Zoom Options" below.

Cumulative Option 4

NO. BINS =

Enter the number of bins desired in the histogram. The limits are from 2 to 255.

A new histogram is displayed. No change occurs in the option list.

Cumulative Option 5

EACH TICK =

Enter the bin count spacing desired between the vertical axis tick marks (only integer values are allowed).

The new histogram is displayed. No change in the option list.

Cumulative Option 6

The current display is changed to a line display. No change in the option list.

Cumulative Option 7

The current display is changed to a bar histogram. No change in the option list.

Cumulative Option 8

The frame displayed upon entry to this routine is redisplayed and control returns to the executive.

Cumulative Histogram Zoom Options

OPTIONS:
1 - ORIG. DISP.
2 - FULL RANGE
3 - LINES
4 - BARS
5 - EXIT
SELECTION =

Enter the number of the desired option.

Cumulative Zoom Option 1

Returns to the display which existed prior to selecting the CUM. HIST. option.

Cumulative Zoom Option 2

Returns to the display which existed prior to selecting the zoom.

Cumulative Zoom Option 3

The current display is changed to a line display. No change in the option list.

Cumulative Zoom Option 4

The current display is changed to a bar histogram. No change in the option list.

Cumulative Zoom Option 5

The frame displayed upon entry to this routine is redisplayed and control returns to the executive.

REGION STATISTICS

FRAME 3

General Description:

This routine computes the mean, standard deviation, mode and population of a region within an image file as described by a region file. The output can be presented either on the keyboard display or on the line printer.

Dialogue:

System	User Response
OUTPUT OPTIONS: 1 - DISPLAY 2 - LINE PRINTER SELECTION =	Enter the option number corresponding to the desired output device.
REGION FILE NAME =	Enter the name associated with the region file which describes the region over which the statistics are to be computed.
INPUT IMAGE NAME =	Enter the name associated with the image file which contains the region of interest.
The statistics are then computed and printed on the specified device. For display output, the following message appears:	
END OF STATISTICS, TYPE CR TO EXIT	Enter a carriage return to return to the frame that was displayed upon entry to this routine.

MULTIREGION STATISTICS

FRAME 3

General Description:

This routine computes the mean, standard deviation, mode, and population of a set of regions within a spectral set of images. These statistics are computed for each region within each of the images. The output can be presented either on the keyboard display or on the line printer. The region files and the spectral set of images are specified via a spectral set file.

Dialogue:

System	User Response
OUTPUT OPTIONS: 1 - DISPLAY 2 - LINE PRINTER	
SELECTION =	Enter the option number corresponding to the desired output device.
SPECTRAL FILE SET NAME =	Enter the name associated with the spectral set file that describes the desired set of region and image files.
The statistics are then computed and printed on the specified device. If the output is on the display and the display is filled prior to the completion of the output, the following message is printed:	
END OF PAGE, TYPE CR FOR NEXT PAGE	Enter a carriage return when ready to proceed to the next page.
When the last page is displayed, the following appears:	
END OF STATISTICS, TYPE CR TO EXIT	Enter a carriage return to redisplay the frame from which this routine was entered.
Control returns to the executive.	

IMAGE ROW INTENSITY PROFILE

FRAME 3

General Description:

This routine displays the intensity profile of any row of any image. The display is presented in histogram format where the horizontal axis represents the column positions and the vertical axis the intensity values. For each display, the x-axis (intensity values) and the range of the data (minimum and maximum intensity value displayed) are listed. Also the row number, the number of columns, the intensity value range for each vertical tick mark, the file name, and the current date and time are listed.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
ROW NUMBER =	Enter the number of the row to be displayed.
START COL =	Enter the number of the first column within the row to be displayed.
NO. OF COLS =	Enter the number of columns to be included in the display.

Histogram is displayed and
the following options are displayed.

OPTIONS:

1 - NEW ROW, COL
2 - NEW START COL
3 - NEW NO. OF COLS
4 - NEW TICKS
5 - LINES
6 - BARS
7 - EXIT

Select the desired option.

Option 1

ROW NUMBER =	Enter the number of the row to be displayed.
START COL =	Enter the number of the first column within the row to be displayed.

New histogram is displayed.

Option 2

START COL = Enter the number of the first column within the row to be displayed.

New histogram is displayed.

Option 3

NO. OF COLS = Enter the number of columns to be included in the display.

New histogram is displayed.

Option 4

EACH TICK = Enter the bin count to be associated with each tick along the x-axis. (Only integer values are permissible.)

New histogram is displayed.

Option 5

The current display is changed to a line connecting the intensity values of each column.

Option 6

The current display is changed to a bar histogram.

Option 7

The frame displayed upon entry to this routine is redisplayed and control returns to the executive.

3.3.5. Frame 4 - Smooth Images

This frame contains options which perform smoothing operations on an image. These operations are performed on the neighborhood of each point within an image. They include the ability of specifying any linear function over the neighborhood.

```
FRM 4-SMOOTH IMAGES

1 - BOX SMOOTH
2 - M x N SMOOTH
3 - WEIGHTED SMOOTH
4 - WGHTD ABSOLUTE VAL SMOOTH
5 - DISPLAY OPTIONS
6 - MASTER FRAME
```

BOX SMOOTH

FRAME 4

General Description:

This routine smooths an image by replacing each point within the image with the average of all points in a square centered about that point. The size of the square is specified by the user. The center of the square (relative to the upper left-hand corner) is given by (N/2)+1 where N is the dimension of the square in rows and columns.

Since edge points do not have a complete neighborhood, values for these missing neighborhood points are set equal to the nearest existing image point. In other words, the edge points are extended outward to provide the required neighborhood.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
BOX SIZE =	Enter the number of rows and columns to be included in the smoothing box.
SMOOTHING IN PROGRESS (Smooth is performed)	
SMOOTHING COMPLETE	

M X N SMOOTH

FRAME 4

General Description:

This routine smooths an image by replacing each point within the image with the average of all points in a rectangle centered about that point. The dimensions of the rectangle are specified by the user. The center point of the rectangle (relative to the upper-left hand corner) is given by

$$(\text{row, col.}) = \left(\frac{M}{2} + 1, \frac{N}{2} + 1\right)$$

where M = row dimension of the rectangle
N = column dimension of the rectangle.

Since edge points do not have a complete neighborhood, values for these missing neighborhood points are set equal to the nearest existing image point. In other words, the edge points are extended outward to provide the required neighborhood.

Dialogue:

System	User Response
INPUT IMAGE NAME =	The file name associated with the image to be smoothed.
OUTPUT IMAGE NAME =	The file name to be assigned to the new image file.
BOX SIZE IS M ROWS BY N COLUMNS M =	The number of rows to be included in the smoothing rectangle.
N =	The number of columns to be included in the smoothing rectangle.
SMOOTHING IN PROGRESS (smooth is performed)	
SMOOTHING COMPLETE	

WEIGHTED SMOOTH

and

WGHTD ABSOLUTE VAL SMOOTH

FRAME 4

General Description:

These routines perform a weighted smooth on an image by replacing each point within the image with a weighted average of all points in a rectangle centered about that point. (See M X N SMOOTH for a definition of the center point.) The weighted average is calculated by forming the product of each element in the weighting array with the corresponding pixel within the rectangle. These products are then summed and divided by the sum of the weights, the sum of the absolute values of the weights, or a user-entered value, whichever is specified by the user. The WEIGHTED SMOOTH changes weighted averages less than zero to zero and weighted averages greater than 255 to 255. The WGHTD ABSOLUTE VAL SMOOTH takes the absolute value of the weighted average. If this result is greater than 255 it is made equal to 255.

The weighting array is specified by the user. The dimensions of this array determine the size of the rectangle over which the smooth is performed. The user has three options available for specifying the weights. First, he may simply enter the name of a file containing a previously entered set of weights. Second, he may enter a new set of weights and save them in a file. Third, he may enter a new set of weights without saving them.

Since edge points do not have a complete neighborhood, values for these missing neighborhood points are set equal to the nearest existing image point. In other words, the edge points are extended outward to provide the required neighborhood.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with image to be smoothed.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
WEIGHT FILE OPTIONS 1 - USE OLD FILE 2 - CREATE NEW FILE 3 - NO FILE SELECTION =	Enter the number of the desired option.

Option 1

WEIGHT FILE NAME = — Enter the file name associated with desired weight array.

DENOMINATOR IS SUM OF:
1 - WEIGHT VALUES
2 - WEIGHT ABSOLUTE VALUES
3 - USER SPECIFIED
SELECTION = — Enter the option number of the desired denominator format.

If the third denominator option is selected, the following is printed:

DENOMINATOR (INTEGER) = — Enter the desired denominator value.

All three denominator options continue at this point.

SMOOTHING IN PROGRESS
(image is smoothed)

SMOOTHING COMPLETE

Option 2

WEIGHT ARRAY IS M ROWS BY N COLUMNS
M = — Enter the row dimension of the weight array to be entered.

N = — Enter the column dimension of the weight array.

WEIGHT FILE NAME = — Enter the name to be assigned to the new weight array.

ENTER WEIGHTS FOR EACH ROW-R1, W2,...WN
ROW 1 =
ROW 2 =
.
.
.
ROW M — Enter the weights for each row of the weight array on one line separated by commas.

WEIGHTED SMOOTH
and WGHTD ABSOLUTE VAL SMOOTH (Continued)

DENOMINATOR IS SUM OF:
1 = WEIGHT VALUES
2 = WEIGHT ABSOLUTE VALUES
3 = USER SPECIFIED
SELECTION = Enter the option number of the desired denominator format.

If the third denominator option is selected, the following is printed:

DENOMINATOR (INTEGER) = Enter the desired denominator value.

All three denominator options continue at this point.

SMOOTHING IN PROGRESS
(image is smoothed)

SMOOTHING COMPLETE

Option 3

Same as Option 2 except that a weight file name is not requested.

3.3.6. Frame 5 - Combine Images

This frame contains options that allow two images to be arithmetically combined on a point-by-point basis. Included is an option that allows one image to be normalized with respect to another.

```
FRM 5-COMBINE IMAGES

1 - AVERAGE IMAGES
2 - SCALED DIFFERENCE
3 - ABSOLUTE DIFFERENCE
4 - SCALED WGHTD COMBINATION
5 - RATIO IMAGES
6 - DISPLAY OPTIONS
7 - MASTER FRAME
```

AVERAGE IMAGES

FRAME 5

General Description:

This routine combines two images to create a new image. The output image is a point-by-point average of the two input images. That is,

$$O_{ij} = (A_{ij} + B_{ij})/2$$

where O_{ij} is the ijth point in the output image.

A_{ij} is the ijth point in the first input image.

B_{ij} is the ijth point in the second input image.

The images being combined must be of equal dimensions.

Dialogue:

System	User Response
FIRST IMAGE NAME =	Enter the file name associated with the first image.
SECOND IMAGE NAME =	Enter the file name associated with the second image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

SCALED DIFFERENCE

FRAME 5

General Description:

This routine computes a scaled difference between two images on a point-by-point basis and creates an output image consisting of the result. That is,

$$O_{ij} = (A_{ij} - B_{ij} + 255)/2$$

where O_{ij} is the ijth point in the output image.

A_{ij} is the ijth point in the first input image.

B_{ij} is the ijth point in the second input image.

The two input images must be of equal dimensions.

Dialogue:

System	User Response
FIRST IMAGE NAME =	Enter the file name associated with the first image.
SECOND IMAGE NAME =	Enter the file name associated with the second image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

ABSOLUTE DIFFERENCE

FRAME 5

General Description:

This routine computes the absolute difference between two images on a point-by-point basis and creates an output image consisting of the result. This can be expressed as,

$$O_{ij} = \left| A_{ij} - B_{ij} \right|$$

where O_{ij} is the ijth point in the output image.

A_{ij} is the ijth point in the first input image.

B_{ij} is the ijth point in the second input image.

The two input images must be of equal dimensions.

Dialogue:

System	User Response
FIRST IMAGE NAME =	Enter the file name associated with the first image.
SECOND IMAGE NAME =	Enter the file name associated with the second image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

SCALED WGHTD COMBINATION

FRAME 5

General Description:

This routine computes the difference between two images on a point-by-point basis, multiplies this difference by a factor and scales the result between 0 and 255. This can be represented by,

$$O_{ij} = 255(P_{ij} - P_{min})/(P_{max} - P_{min})$$

where $P_{ij} = N_1 A_{ij} + N_2 B_{ij}$

P_{min} is the minimum value of the P_{ij}'s.

P_{max} is the maximum value of the P_{ij}'s.

A_{ij} is the ijth point in the first input image.

B_{ij} is the ijth point in the second input image.

O_{ij} is the ijth point in the output image.

N_1 and N_2 are constants between -64 and +64 entered by the user.

If P_{max} and P_{min} are found to be equal, no further calculations are made and the output image is not created. The values of P_{max} and P_{min} are listed on the display.

The two input images must be of equal dimensions.

Dialogue:

System	User Response
FIRST INPUT IMAGE NAME =	Enter the file name associated with the first image.
SECOND INPUT IMAGE NAME =	Enter the file name associated with the second image.
MULTIPLIERS MAY RANGE BETWEEN -64 AND 64 FIRST MULTIPLIER =	Enter the desired value for N_1 in the above expression.
SECOND MULTIPLIER =	Enter the desired value for N_2 in the expression above.

MIN COMBINATION = m

MAX COMBINATION = n
(m and n are P_{min} and P_{max} respectively in the expression above.)

If $P_{max} = P_{min}$, the following message is printed and execution is terminated.

OUTPUT RANGE = Ø: OUTPUT NOT CREATED

Otherwise,

OUTPUT IMAGE NAME = Enter the file name to be assigned to the new image file.

RATIO IMAGES

FRAME 5

General Description:

This routine performs a normalization operation on a set of two images. One image is selected as the reference and the other one is normalized with respect to it. A new file is created for the output result. The following operations are performed at each point in the images:

$$O_{ij} = \frac{255(P_T - P_{min})}{P_{max} - P_{min}}$$

where

$$P_T = 256 \frac{I_{ij}}{P_{ref}}$$

I_{ij} is the ijth point of the input image

P_{ref} is the ijth point of the reference image

P_{max} is the maximum value of the P_T's

P_{min} is the minimum value of the P_T's

O_{ij} is the ijth point of the output image

If P_{ref} is zero, the division to determine the value of P_T is not accomplished (i.e., $P_T = 256\, I_{ij}$). If P_{max} is found to be equal to P_{min}, the program exits prior to creating an output file.

The two input images must be of equal dimensions.

Dialogues:

System	User Response
NOTE: NO DIVISION IS PERFORMED AT PIXEL POSITIONS WHERE REF. IMAGE IS Ø.	
REFERENCE IMAGE NAME =	Enter the file name associated with the image to be used as the reference image.
INPUT IMAGE NAME =	Enter the file name associated with the second image in the set.

RATIO IMAGES (Continued)

If $P_{max} = P_{min}$, the following message is printed and control is returned to the executive.

OUTPUT RANGE=Ø; OUTPUT NOT CREATED

Otherwise,

OUTPUT IMAGE NAME = *Enter the name to be assigned to the new image file.*

3.3.7. Frame 6 - Noise Reduction

This frame contains options which are designed to remove certain types of noise from an image. Such noise may have been introduced during film processing and/or digitization.

```
FRM 6-NOISE REDUCTION

1 - MODAL REPLACEMENT
2 - ODD DOT
3 - ODD LINE
4 - DISPLAY OPTIONS
5 - MASTER FRAME
```

MODAL REPLACEMENT

FRAME 6

General Description:

This routine is designed to modify all points in an image that differ from the majority of their eight neighbors. The neighborhood of each point is examined to determine the most frequently occurring grey value (mode). If the center point is of a different grey value, it is made equal to the modal value. If no grey value occurs most frequently, the center point is not changed. If the surrounding point distribution is multimodal, but the center point is not one of the modes, the center is made equal to the value of the first mode encountered in a left-to-right, top-to-bottom scan of the surrounding points.

Since the edge points do not have a complete eight-point neighborhood, they are copied to the output file unchanged.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

ODD DOT

FRAME 6

General Description:

This routine removes noise in the form of isolated pixels which are significantly different from one or more or the average of their eight neighbors. The pixels are replaced with the average of the neighbors with which they differ or with the average of all eight neighbors in the case where the comparison is made to the average.

The user specifies a threshold value with which each difference is compared as well as the basis for computing the difference (i.e., difference between a pixel and each of its eight neighbors or between a pixel and the average of its eight neighbors).

Since the edge points do not have an eight point neighborhood, they are simply transferred to the output file unaltered.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
THRESHOLD =	Enter the threshold with which the differences are to be compared.
COMPARE TO AVERAGE(Y OR N)?	Enter "Y" to compare each point with the average of its eight neighbors or "N" to compare each point with all of its eight neighbors.

Y Option

No further dialogue.

N Option

NO. OF NEIGHBORS TO EXCEED THRESH =	Enter number of neighbors with which a point must differ by more than the threshold amount before it is changed to the average of the neighbors with which it differs.

ODD LINE

FRAME 6

General Description:

This routine removes noise in the form of a line which is a maximum of one point wide. This is accomplished by operating within the 3 by 3 neighborhood of each point in the image. Each point is compared to each of its eight neighbors to determine if a neighbor is similar or different. The points are similar if their grey value difference does not exceed a user-specified threshold. If two "similar" neighbors are adjacent, the center point is replaced with the average of the "different" neighbors.

The user is given the option to remove either low or high noise. Low noise refers to lines which are darker (lower grey value) than the image and high noise refers to lines which are brighter (higher grey value) than the image.

Since the edge points do not have an eight point neighborhood, they are simply transferred to the output file unaltered.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
TYPE OF NOISE: 1 - LOW NOISE 2 - HIGH NOISE SELECTION =	Select the type of noise lines to be removed.
THRESHOLD =	Enter the threshold with which the differences are to be compared.

3.3.8. Frame 7 - Edge Detection

This frame contains options which are designed to detect and manipulate edges of objects which typically appear as grey level gradients within an image. The three edge detection routines accept grey value images as input and produce binary images as output. Binary images are defined as images of two values, Ø or 255. The remaining routines attempt to refine the detected edges by removing extraneous edges and filling in missing or broken edges. One final routine provides line printer listings of the images.

```
FRM 7-EDGE DETECTION

1 - POINT EDGE DETECTION
2 - AREA EDGE DETECTION
3 - AREA EDGE DETECTION MAX
4 - SIMPLE FILL IN
5 - ADAPTIVE FILL IN
6 - CLOSED CURVE
7 - LIST BINARY IMAGE
8 - DISPLAY OPTIONS
9 - MASTER FRAME
```

POINT EDGE DETECTION

FRAME 7

General Description:

This routine is designed to detect gradients within an image which exceed a user-specified threshold. The gradient test is made within a three by three neighborhood about each point and is therefore very local in nature. The actual test is accomplished by comparing the center point with user-specified neighbors in the three by three neighborhood. If the difference between any pair is greater than the specified threshold, the point in the output file corresponding in position to the center point is set equal to 255. Otherwise, the output value is zero.

Since edge points do not have a three by three neighborhood, they are all set to zero in the output image.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.
SELECT NEIGHBOR POINTS FOR COMPARISON REFERENCE NUMBERS ARE: 6 7 8 5 x 1 4 3 2	
TERMINATE LIST WITH CNTRL-Z NEIGHBOR =	Enter the reference numbers corresponding to the desired neighbors. Each number must be on a separate line. The selections are terminated by typing a "Z" while holding down the CNTL key. This must be followed by a carriage return.
THRESHOLD =	Enter the desired threshold value with which the neighbor differences are to be compared.

AREA EDGE DETECTION

and

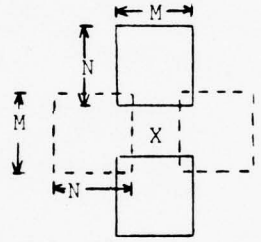
AREA EDGE DETECTION MAX

FRAME 7

General Description:

These routines are designed to detect gradients within an image which exceed a user-specified threshold. The gradient test is made between user specified rectangular area pairs (left-right and top-bottom) for each point in the image. The AREA EDGE DETECTION routine forms the basis for the AREA EDGE DETECTION MAX routine and will therefore be discussed first.

The following diagram describes the areas referenced in the gradient detection operation that is performed at each pixel location:



The user specifies the M and N dimensions of the rectangles in terms of picture elements. The routine calculates the average value of the points within each rectangle and then computes the difference between the horizontal rectangle pair and the vertical rectangle pair. If either difference exceeds a user specified threshold, a value of 255 is assigned to the point in the output file whose position corresponds to the position of point "X" (in the above diagram) in the input file. Otherwise, the output value is made equal to zero. This is the final output of the AREA EDGE DETECTION routine.

The AREA EDGE DETECTION MAX routine proceeds in the previously described manner, except that the decision concerning the output value of point "X" depends on one further processing step. It may already be apparent to the reader that several points along a gradient may have an output value of 255 based upon the previously described algorithm. This results in rather broad edges of objects appearing in the binary output image. The AREA EDGE DETECTION MAX routine attempts to refine the output image by reducing these edges to one pixel in width. This is accomplished by first recording all tentative edge points, as defined by the previous criteria, which result from the vertical box pairs. At such points we assume that there is an edge running along or near to the row direction. The neighboring points are checked to see if there are other edge points in the same column position. When all

neighboring edge points are found in that column position there will exist a series of edge points bordered by non-edge points. For this series, the point where the maximum difference between the mean values of the vertical box pair occurs is marked as the only true edge point. This point takes on an output value of 255 and all other points in the series become zero.

A completely analogous procedure is followed for the horizontal box pair. In this case, edges are assumed to run along or near to the column direction. The final output consists of the union of the points resulting from the two box pairs.

Dialogue:

System	User Response
NUMBER OF ROWS IN HORIZ. BOXES =	Enter the vertical dimension of the horizontal box pair (or horiz. dimension of vert. pair) in terms of picture elements.
NUMBER OF COLS. IN HORIZ. BOXES =	Enter the horizontal dimension of the horizontal box pair (or vert. dimension of vert. pair) in terms of picture elements.
THRESHOLD =	Enter the desired threshold value with which the box pair differences will be compared.
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the desired output image.

SIMPLE FILL IN

and

ADAPTIVE FILL IN

FRAME 7

General Description:

These routines are designed to restore breaks in object edges which occur in binary images as a result of incomplete edge detection. Both routines operate on a three by three neighborhood of a point and are therefore local in nature. The basic algorithm employed examines the three by three neighborhood of each non-edge point within the image in a clockwise manner. If this examination reveals point sequences of one or more edge, one or more non-edge, one or more edge and one or more non-edge, the center point will be changed to an edge point (grey value 255). Otherwise, the point will remain at zero. There are two special cases where these criteria are satisfied but the point is not changed. These are illustrated below:

X	X	X
	P	
X	X	X

X		X
X	P	X
X		X

where X is an edge point and P is the point in question.

The ADAPTIVE FILL IN differs from the SIMPLE FILL IN in only one way. It operates on the union of the input image with the current state of the output image. That is, if a non-edge point is made an edge point, it will be included as an edge point for all future considerations.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the name to be assigned to the new image file.

CLOSED CURVE

FRAME 7

General Description:

This routine operates on a binary image and produces a new image which contains only those edge points (binary 1) which are part of a closed curve. All points which are not part of a closed curve are assigned an output value of zero.

The algorithm operates on the three by three neighborhood of each edge point. If all of the eight surrounding points are non-edge, the point will, of course, be changed to non-edge. If some of the points are non-edge, the eight point surround will be examined to see if removing the center point will cause two edge points to be separated. If it does not, the point will be made a non-edge point. This condition is found by selecting any edge point in the surround and checking, in a clockwise manner, the other seven points. If these points have a configuration of one or more non-edge, one or more edge and one or more non-edge, the point is not removed. The following three diagrams show some examples where the edge point would not be removed:

E	E	N
E	X	*
E	N	E

E	N	N
N	X	*
E	N	N

*	N	N
N	X	N
N	E	N

where E = edge point
N = non-edge point
X = point under consideration
* = first edge point found

The following diagrams show some examples where the point would be removed:

N	N	N
N	X	N
N	*	N

N	N	*
N	X	E
N	E	E

E	E	*
E	X	E
E	E	E

where the symbols are as defined previously.

CLOSED CURVE (Continued)

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
OUTPUT IMAGE NAME =	Enter the name to be assigned to the new image file.

LIST BINARY IMAGE

FRAME 7

General Description:

This routine allows the user to list the contents of binary image files on the line printer. The binary zero pixels are listed as spaces and the binary one values are listed as asterisks. The pixels are printed in positions relative to their locations within the image array. The user specifies the image starting row and column at which the listing is to begin and the number of rows and columns to be included in the listing. The size of the image is displayed on the Tektronix to aid the user in making these selections.

If the number of columns to be printed exceeds the width of the line printer, the remaining columns are listed on as many additional sheets as necessary. The starting row and column for each sheet is printed at the top of the listing. The image name, size, and header text are also listed.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the image to be listed.
IMAGE SIZE R, C = m, n STARTING R, C =	Enter the desired starting row and column on one line separated by a comma.
NUMBER R, C TO PRINT =	Enter the number of rows and columns to be listed. Entries are on one line separated by a comma.

3.3.9. Frame 8 - Transforms

This frame contains options related to transform operations. One type of transform is provided and that is the Hadamard transform. This is a two-dimensional transform that is performed on an image file. The resulting output is a two-dimensional array in the frequency domain upon which the filtering options operate. Filters are designed as two-dimensional weighting arrays that are applied to the transforms by forming the product between the two on a point-by-point basis.

```
FRM 8-TRANSFORMS

1 - HADAMARD TRANSF
2 - GENERATE FILTER
3 - APPLY FILTER
4 - DISPLAY OPTIONS
5 - MASTER FRAME
```

HADAMARD TRANSF

FRAME 8

General Description:

This routine performs a two-dimensional Hadamard transform on an image or a Hadamard transform of an image. In the latter case, the operation performed is actually the inverse Hadamard transform and an image is the resulting output.

When performing the transform on an image, the transform can be stored in a single or double precision integer file. The desired precision is selected by the user. An option is also available for creating an image file in addition to the transform file. This image is simply the transform file normalized between two user-specified limits. Values below the lower limit are set to zero and values above the upper limit are set to 255. As an aid in selecting these limits, the histogram of the transform across its entire range is presented on the keyboard display.

In all cases, the transform is performed on each row of the file and the rows are scaled if overflow occurs. Then the transform is performed on each column of that result and the columns are scaled if overflow occurs.

For a further discussion of the Hadamard transformation, the user is referred to H. F. Harmuth, Transmission of Information by Orthogonal Functions, Second Edition.

Dialogue:

System	User Response
INPUT FILE OPTIONS 1 - IMAGE 2 - HADAMARD SELECTION =	Enter the number of the desired option.
	Option 1
INPUT IMAGE NAME =	Enter the file name associated with the desired image.

HADAMARD TRANSF (Continued)

HADAMARD TRANSFORM FILE OPTIONS:
1 - SINGLE PRECISION INTEGER
2 - DOUBLE PRECISION INTEGER
SELECTION =

Enter the number of the option which corresponds to the desired accuracy with which the output transform is to be stored.

OUTPUT HADAMARD TRANSFORM NAME =

Enter the file name to be assigned to the new Hadamard transform.

TRANSFORM IN PROGRESS
HADAMARD IMAGE FILE OPTIONS:
1 - CREATE IMAGE FILE
2 - NO FILE
SELECTION =

Enter the number of the desired option.

Option 2 causes the message "TRANSFORM COMPLETE" to be printed and control returns to the executive. Option 1 continues immediately below.

OUTPUT IMAGE NAME =

Enter the file name to be assigned to the new Hadamard image file.

If the range of values in the output transform is zero, the following is printed and no further processing is done:

RANGE IN TRANSFORM IS ZERO.
NO IMAGE FILE CREATED.

Otherwise, the transform histogram is displayed and the following is printed:

SELECT SCALING LIMITS WITH CURSOR.
POSITION AT LOW LIMIT AND TYPE L.
POSITION AT HIGH LIMIT AND TYPE H.
RESELECT EITHER LIMIT AS DESIRED.
TYPE CAR. RET. WHEN COMPLETE.

Select the desired scaling limits as directed. Selected values will be printed at the cursor position. The upper limit must be larger than the lower limit. Positioning the cursor beyond the limits of the histogram will cause the nearest limit to be assumed as the desired value. Repeated selections are allowed. However, only the last selection for a particular

limit is used. If a carriage return is entered before either limit is specified, the limits will be set equal to the minimum and maximum values displayed.

SCALING IN PROGRESS

Image scaling is performed.

TRANSFORM COMPLETE

Option 2

(From initial option list)

INPUT HADAMARD TRANSFORM NAME = Enter the file name associated with the desired Hadamard transform array.

TRANSFORM IN PROGRESS

If the range of values in the resulting transform is zero, the following is printed and no further processing is done:

RANGE IN TRANSFORM IS ZERO.
NO IMAGE FILE CREATED.

Otherwise processing continues below.

OUTPUT IMAGE NAME = Enter the file name assigned to the new Hadamard image file.

TRANSFORM IN PROGRESS

If the range of values in the output transform is zero, the following is printed and no further processing is done:

RANGE IN TRANSFORM IS ZERO.
NO IMAGE FILE CREATED.

Otherwise the transform histogram is displayed and the following is printed:

SELECT SCALING LIMITS WITH CURSOR
POSITION AT LOW LIMIT AND TYPE L.
POSITION AT HIGH LIMIT AND TYPE H.
RESELECT EITHER LIMIT AS DESIRED.
TYPE CAR. RET. WHEN COMPLETE.

Select the desired scaling limits as directed. Selected values will be printed at the cursor position. The upper limit must be larger than the lower limit. Positioning the cursor beyond the limits of the histogram will cause the nearest limit to be assumed as the desired value. Repeated selections are allowed. However, only the last selection for a particular limit is used. If a carriage return is entered before either limit is specified, the limits will be set equal to the minimum and maximum values displayed.

SCALING IN PROGRESS

Image scaling is performed.

TRANSFORM COMPLETE

GENERATE FILTER

FRAME 8

General Description:

This routine allows the user to generate a filter file. A filter is basically a weighting array that is applied to another array such as that resulting from a transform of an image. The application of the filter is typically accomplished by forming the product of the filter with the second array on an element-by-element basis.

The user is provided with the capability to specify the elements of the filter as a function of their position within the array. This function is specified by the user via one or more "FORTRAN-like" statements. These statements can specify a filter in one of two ways. The first method allows statements to be written which define the output array values as a function of row and column positions. The second method provides for statements which are a function of only the euclidian distance from the upper left-hand corner of the image (point 0, 0 which is outside the image). In the latter case, the filter function is simply a surface generated by a rotation of a curve, defined as a function of one variable, about the Z-axis. A third option allows a previously created and saved filter function of either of the above types to be retrieved for re-use.

The statements which define the desired function may contain the following operators:

Operator	Operation	Level
EXP(X)	exponentiation (e^X)	7
LOG(X)	log base 10 of X	7
LN(X)	log base e of X	7
-	unary minus	6
*	multiplication	5
/	division	5
+	addition	4
-	subtraction	4
=	equality	3
<	less than	3
>	greater than	3
<= or =<	less than or equal	3
>= or =>	greater than or equal	3
<> or ><	not equal	2
Λ	AND	2
!	OR	1

The level indicates the order in which the operation is performed. As with FORTRAN, the order can be specified through the use of parentheses.

Three types of statements can be used. The first type is identical to the FORTRAN assignment statement which is of the form

variable = expression

where variable is any symbol of one to six characters, expression is any legal arithmetic expression and = is the replacement operator. The expression may contain constants, variables from a previous assignment statement, or dependent variables (row and column or euclidian distance).

The second statement type is of the form

IF(expression) assignment statement

and is identical to the FORTRAN logical IF statement. If the expression is true, the assignment statement is executed. Otherwise, execution continues with the next statement in order. The expression can consist of both arithmetic and logical operators but it must yield a logical result. The assignment statement is as defined previously.

The third statement type is of the form

IF GO(expression) assignment statement

This statement is identical to the IF statement except that when the expression is true for a given array element and the assignment statement has been evaluated, all statements following the IF GO statement are ignored for that element.

The following is an example of a possible set of statements:

```
OUT = D*D
IF GO(D > 128.)OUT = 4*D-6
X = (2.*D)/ D + CON
IF GO(D > 64.)OUT = 2*D
IF GO(D > 32.)OUT = X/4
X = X/D
IF(D > =16)OUT = X*X
```

This set defines a different function of the euclidian distance "D" for each of the intervals:

```
  0 - 15
 16 - 32
 33 - 64
 65 - 128
129 - ∞
```

The symbol "OUT" represents the output value for each inserted value of D. The symbol "CON" is treated as a constant whose value is assigned by the user

just prior to evaluating the expression for all points in the filter. The only special symbol is "D" which always represents the euclidian distance. All other symbols are at the discretion of the user. If the statements had defined a function of row and column, the special symbols "R" for row and "C" for column would have been used.

It should be noted that an implied "DO" loop exists for every set of statements entered. That is, the set of statements is executed once for each element position in the array.

To enable the user to inspect the filter function as defined by a set of statements, cross sections of the resulting surface may be plotted on the Tektronix. The user must be cautioned that these cross sections in no way define the array size in the final output filter file. They are merely a tool by which he may examine the output of his function along any line in the plane of the output array. The cross section is selected by entering the two end-points (row, column) in the plane of the array which defines the desired cross section. The horizontal axis in the resulting display is the straight line between the two selected points. The vertical axis represents the filter function values along the line. The vertical axis scale is determined by the range of the filter function along the cross section. The maximum and minimum values are displayed at the extremes of the vertical axis and the coordinates defining the cross section are displayed at the extremes of the horizontal axis. If the function crosses the zero axis, the zero axis is plotted and labeled as such.

After the display is presented, the user may:

1. Accept the function, save it in a file, and generate a filter file of specified dimensions from the function.

2. Display a new cross section, possibly reassigning values to constants if any were used.

3. Reject the function and start over.

4. Exit the routine with no further filter generation.

Dialogue:

System	User Response
1 = COMPILE 1-DIM FUNCTION 2 = COMPILE 2-DIM FUNCTION 3 = USE EXISTING FUNCTION 4 = EXIT OPTION =	Enter the number of the desired option.

GENERATE FILTER (Continued)

Option 1

```
INDEPENDENT VARIABLE = D
D=DISTANCE FROM POINT (Ø,Ø)
THIS POINT IS OUTSIDE ARRAY.

ENTER STATEMENTS. "&" AS LAST CHAR.
ALLOWS A STATEMENT TO BE CONTINUED ON
NEXT LINE.
ENTER A STATEMENT
```

Enter one statement. If it is too long for one line, enter an "&" as the last character to allow it to be continued on the next line.

The following line is repeatedly printed to allow additional statements to be entered:

```
ENTER A STATEMENT
(CAR. RET. TO END)
```

Enter additional statements as desired. A carriage return alone terminates input.

Execution continues at "Options 1 to 3 Cont." below, upon entry of a carriage return alone.

Option 2

```
INDEPENDENT VARIABLES=R,C
R=ROW (1ST ROW IS R=1)
C=COLUMN (1ST COLUMN IS C=1)

ENTER STATEMENTS.  "&" AS LAST CHAR.
ALLOWS A STATEMENT TO BE CONTINUED
ON NEXT LINE.
ENTER A STATEMENT
```

Enter one statement. If it is too long for one line, enter an "&" as the last character to allow it to be continued on the next line.

The following line is repeatedly printed to allow additional statements to be entered:

```
ENTER A STATEMENT
(CAR. RET. TO END)
```

Enter additional statements as desired. A carriage return alone terminates input.

GENERATE FILTER (Continued)

Execution continues at "Options 1 to 3 Cont." below, upon entry of a carriage return alone.

Option 3

FUNCTION FILE NAME =

Enter the file name associated with the desired filter function.

FUNCTION FILE HEADER =
(header text is listed here if any)

INSPECT COMPILED STATEMENTS (Y=YES)

Enter "Y" if it is desired to list the statements on the keyboard display. Enter "N" if the listing is not desired.

Statements are listed if "Y" is entered.

USE THIS FILE?(Y-N):

Enter "Y" if the selected file is to be used. Enter "N" if it is not to be used.

A "Y" response causes execution to continue at "Options 1 to 3 Cont." below. An "N" response causes execution to return to the initial option list presented upon entry.

Option 4

The routine exits to the executive with no further action.

Options 1 to 3 Cont.

If any constants are undefined the following is printed:

ENTER UNDEFINED CONSTANTS
Symbol =
Each symbol is listed in order until all constant symbols are defined.

Enter the desired value to be associated with the symbol listed.

ENTER ENDPOINTS OF LINE DEFINING CROSS SECTION; 1ST PT:R,C=

Enter the row and column values on one line separated by a comma which define the first endpoint of the cross section.

GENERATE FILTER (Continued)

2ND PT.(DIFFERENT FROM 1ST):R,C=	Enter the row and column values which define the second cross section endpoint.
Cross section is displayed and the following options appear: A-ACCEPT FUNCTION D-DISPLAY NEW CROSS SECTION R-REJECT FUNCTION E-EXIT	Enter the letter corresponding to the desired option.

Option A

If Option 3 was selected upon entry, then the next two queries are skipped.

SAVE FUNCTION AS A FILE?(Y=YES):	Enter "Y" if the function entered is to be saved for future use. Otherwise enter "N".
The next query is skipped if "N" is entered. FUNCTION FILE NAME=	Enter file name to be assigned to the function.
FILTER FILE SIZE:R,C=	Enter the vertical and horizontal dimensions of the filter file that is to be created.
FILTER FILE NAME =	Enter the file name to be assigned to the new filter file.

Exit to the executive.

Option D

If the statements being used contain any constant symbols, the following query is made:

USE PREVIOUSLY ENTERED CONSTANTS?(Y=YES)	Enter "Y" if the values previously entered for the constants are acceptable. Otherwise, enter "N".

If "N" is entered execution returns to "Option 1 to 3 Cont." above. If "Y" is entered execution returns to the second query of "Options 1 to 3 Cont." above.

If no constants are involved execution returns to the second query also.

Option R

Execution returns to the initial option list presented upon entry.

Option E

The routine exits to the executive with no further action.

APPLY FILTER

FRAME 8

General Description:

This routine forms the product, on an element by element basis, between a filter file and any other file which is in an array format. The horizontal and vertical dimensions (in terms of the basic element) of the latter file must correspond to the dimensions of the filter file. The result is stored in an output file which is of the same type and dimension as the latter file. If the output is in integer format, all values less than zero are made equal to zero and all values greater than the precision of the element (byte, word, or double word) are made equal to the maximum unsigned value of the element.

Dialogue:

System	User Response
FILTER FILE NAME =	Enter the file name associated with the desired filter file.
INPUT FILE NAME WITH EXT =	Enter the name and extension of the file with which the product is to be formed.
OUTPUT FILE NAME =	Enter the file name to be assigned to the new output file.

3.3.10. Frame 9 - Feature Extraction

This frame contains options which are used in the process of forming feature vectors for logic creation and evaluation. The first step in the process is to define a set of images as a spectral file set. This list of images is recorded in a "spectral set" file.

The vector file created from the spectral set can be one of two types. A design vector file consists of vectors formed on the basis of selected points within one or more regions of the spectral scene. Each region is listed in the spectral set file and has an associated class symbol. Therefore, each vector is identified as belonging to a particular class. This type of vector is required for designing logic.

The second type is called a test vector file. In this case a vector is created for each point within the spectral scene. No provision is made for assigning class symbols and therefore such vectors cannot be used for logic design. However, they can be classified by a logic that was created on a design set to evaluate the performance of the logic. The results of such an application are then viewed by creating a thematic map. This is simply an image where there is a one-to-one correspondence between an image pixel and a vector. Each pixel is assigned a grey value on the basis of the classification of the corresponding vector by the logic.

The classification of the design vectors can also be viewed via a thematic map. In this case only a subset of the image points represent vectors. Also, in the creation of the design vectors, the row and column indices must be included to allow their position within the thematic map to be retained.

Since it is often desirable to design or apply logic on vectors from several spectral scenes, the ability to specify a set of vector files is included. This specification is recorded in a "vector set" file. All references to vector sets must be made through this file type.

```
FRM 9-FEATURE EXTRACTION

1 - SPECIFY SPECTRAL FILE SET
2 - SPECIFY VECTOR FILE SET
3 - CREATE SPEC. DESIGN VEC. FILE
4 - CREATE SPEC. TEST VEC. FILE
5 - DISPLAY OPTIONS
6 - MASTER FRAME
```

SPECIFY SPECTRAL FILE SET

FRAME 9

General Description:

This routine allows the user to create a new spectral set file or to edit an existing one. A spectral set file contains a list of names of image files that comprise one spectral image set. Also included are names of region files describing areas within the spectral set from which feature vectors can be formed. Each region file has an associated class symbol and a data reduction factor. This factor simply allows a subset of the points within the region to be used for forming vectors.

Note that this option does not create vector files.

Dialogue:

System	User Response
OPTIONS: 1 - CREATE NEW SET 2 - EDIT PREVIOUS SET	
SELECTION =	Enter the number of the desired option.
	Option 1
SPECTRAL IMAGE NAME =	Enter the name associated with an image in the spectral file set. This query repeats until all names have been entered. The list is terminated by typing a carriage return alone in response to the query.
The above query is repeated until the user responds with a carriage return alone.	
REGION NAME =	Enter the name associated with a region file which describes an area in the spectral file set. A carriage return alone indicates that no more names are to be entered.
If only a carriage return is entered, control transfers to Option 2 below.	

SPECIFY SPECTRAL FILE SET (Continued)

CLASS SYMBOL = — Enter the character that is to be assigned as the class symbol for this region.

EVERY NTH POINT WITHIN REGION IS USED. N = — Enter the desired data reduction factor for this region.

The last three queries are repeated until the user enters a carriage return alone in response to the request for a region name.

Option 2

SPECTRAL FILE SET NAME = — Enter the name associated with the spectral set file which is to be edited.

Edit Options

OPTIONS:

1 - INSERT NAME
2 - REPLACE NAME
3 - DELETE NAME
4 - LIST ON TEKTRONIX
5 - LIST ON LINE PRINTER
6 - EXIT

SELECTION = — Enter the number of the desired option.

Edit Option 1

INSERT AS NAME NO. = — Enter the number of the position at which the name is to be inserted. Current position numbers can be observed via Edit Options 4 and 5.

NEW FILE NAME WITH EXTENSION = — Enter the name and extension (include device and unit number if other than the default) of the file name to be added to the set.

If a region file name was entered, the following two queries are made:

CLASS SYMBOL = — Enter the character that is to be assigned as the class symbol for this region.

EVERY NTH POINT WITHIN REGION IS USED. N =

Enter the desired data reduction factor for this region.

For both image and region files, the new entry is made in the file and the routine returns to allow another selection to be made from the Edit Options list.

Edit Option 2

REPLACE FILE NO. =

Enter the number of the name to be replaced. Current number assignments can be observed via Edit Options 4 and 5.

NEW FILE NAME WITH EXTENSION =

Enter the name and extension (include device and unit number if other than the default) of the replacement file name.

If a region file name was entered, the following two queries are made:

CLASS SYMBOL =

Enter the character that is to be assigned as the class symbol for this region.

EVERY NTH POINT WITHIN REGION IS USED. N =

Enter the desired data reduction factor for this region.

For both image and region files, the replacement is made in the file and the routine returns to allow another selection to be made from the Edit Options list.

Edit Option 3

NAME NO. TO DELETE =

Enter the number of the file name which is to be deleted. Current number assignments can be observed via Edit Options 4 and 5.

The specified name is removed and the routine returns to allow another selection to be made from the Edit Options list.

Edit Option 4

The keyboard display is cleared and the contents of the vector file set are listed. If there are more entries than will fit on the display, the following is printed:

END OF PAGE, TYPE CR FOR NEXT PAGE = Enter a carriage return for a display of the next page.

The above continues until the entire contents of the file have been displayed. When the last page is displayed, the following is printed:

END OF DIRECTORY, TYPE CR TO EXIT = Enter a carriage return to return to the point where the edit options are displayed.

After a carriage return is entered, the Edit Options list is redisplayed to allow another selection to be made.

Edit Option 5

The contents of the vector set file are listed on the line printer. The routine then returns to allow another selection to be made from the Edit Options list.

Edit Option 6

The new or edited file is stored on the disk. Control returns to the executive.

SPECIFY VECTOR FILE SET

FRAME 9

General Description:

This routine allows the user to specify the vector files to be included in a vector file set. Either a new vector set file can be created or an existing one can be edited.

A vector set file describes the names of the vector files in a vector file set and the devices on which they are stored. All logic creation operations are performed on sets of vector files as described by a given file of this type.

Dialogue:

System	User Response
OPTIONS: 1 - CREATE NEW SET 2 - EDIT PREVIOUS SET	
SELECTION =	Enter the number of the desired option.
	Option 1
VECTOR FILE NAME =	Enter the name associated with the desired vector file. The device and unit number should be included if the file resides on a device other than the default device and unit.
The last request is repeated to allow entry of all names in the vector file set. When complete, a "carriage return only" response will terminate this input.	
ENTER TEXT FOR HEADER TEXT =	Enter the text to be inserted in the header of the vector set file. Multiple lines are allowed. The text is terminated by typing a carriage return as the first character of a new line of text.
The last line is repeated to allow multiple lines to be entered.	

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SPECIFY VECTOR FILE SET (Continued)

Continue at **Option 2** below.

Option 2

VECTOR FILE SET NAME =

Enter the name associated with the vector set file which is to be edited.

Edit Options

OPTIONS:

1 - INSERT NAME
2 - REPLACE NAME
3 - DELETE NAME
4 - LIST ON TEKTRONIX
5 - LIST ON LINE PRINTER
6 - EXIT

SELECTION =

Enter the number of the desired option.

Edit Option 1

INSERT AS NAME NO. =

Enter the number of the position at which the name is to be inserted. Current position numbers can be observed via Edit Options 4 and 5.

NEW FILE NAME =

Enter the name (with device and unit number if other than the default) of the vector file to be added to the set.

The new name is inserted and the routine returns to allow another selection to be made from the Edit Options list.

Edit Option 2

REPLACE NAME NO. =

Enter the number of the name to be replaced. Current number assignments can be observed via Edit Options 4 and 5.

NEW FILE NAME =

Enter the name (with device and unit number if other than the default) of the vector file name which is to replace the specified name.

The old name is replaced by the new name and the routine returns to allow another selection to be made from the Edit Options list.

Edit Option 3

NAME NO. TO DELETE = Enter the number of the file name which is to be deleted. Current number assignments can be observed via Edit Options 4 and 5.

The specified name is removed and the routine returns to allow another selection to be made from the Edit Options list.

Edit Option 4

The keyboard display is cleared and the contents of the vector file set are listed. If there are more entries than will fit on the display, the following is printed:

END OF PAGE, TYPE CR FOR NEXT PAGE = Enter a carriage return for a display of the next page.

The above continues until the entire contents of the file have been displayed. When the last page is displayed, the following is printed:

END OF DIRECTORY, TYPE CR TO EXIT = Enter a carriage return to return to the point where the edit options are displayed.

After a carriage return is entered, the Edit Options list is redisplayed to allow another selection to be made.

Edit Option 5

The contents of the vector set file are listed on the line printer. The routine then returns to allow another selection to be made from the Edit Options list.

Edit Option 6

The new or edited file is stored on the disk. Control returns to the executive.

CREATE SPEC. DESIGN VEC. FILE

FRAME 9

General Description:

This routine allows the user to create a vector file from selected regions within a set of spectral images or to add spatial measurements to an existing vector file which was also created from selected regions within a set of spectral images. When creating a new file, a vector is formed for the pixels within each specified region according to the data reduction factor in the spectral set file (see SPECIFY SPECTRAL FILE SET). The elements of these vectors consist of the corresponding pixels from each of the images in the spectral set. Spatial measurements may be added to each of the vectors when creating a new file or they may be added to an existing file. These measurements may consist of the mean, deviation, median, low, high and/or range of the values within a neighborhood about the vector position for one or more of the images in the set. The value(s) to be computed, the size of the neighborhood(s) and the image(s) from which to obtain the neighborhood pixels are all specified by the user. Each type of measurement selected can be calculated for one or more images. One measurement is obtained per type per image. For region edge points, only those pixels within the region are used for the calculations.

For new vector files, the user is allowed to specify the accuracy with which the vector elements are to be stored. Also, the row and column values corresponding to the vector's location within the spectral images can be optionally included with each vector. This information is required if a thematic map is to be created following classification of the vectors.

When adding to an existing file, the number of spectral and spatial measurements which make up the vectors is provided for the user's information.

Dialogue:

System	User Response
OPTIONS:	
1 - CREATE NEW FILE 2 - ADD TO OLD FILE	
SELECTION =	Enter the number of the desired option.

CREATE SPEC. DESIGN VEC. FILE (Cont.)

Option 1

SELECT ACCURACY DESIRED

1 - INTEGER BYTE
2 - INTEGER WORD
3 - FLOATING POINT

SELECTION =

Enter the option number corresponding to the desired accuracy.

INCLUDE ROW,COL VECTOR INDICES (Y OR N)?

Enter a "Y" if row and column information should be included in the header of each vector. Otherwise, enter an "N".

SPECTRAL FILE SET NAME =

Enter the name associated with the spectral set file that describes the desired spectral image set.

REGION FILE NAME NO. OF VECTORS
Dev:Filename.REG n

(The last line is repeated for each region file in the spectral file set. "Dev:" refers to the device and unit number, "Filename" refers to the name of the region file and n is the number of vectors formed from the region.)
TOTAL NUMBER OF VECTORS = m

(Where m is the total number of vectors created.)

Continue at "Options 1 and 2 Cont." below.

Option 2

VECTOR FILE NAME =

Enter the name associated with the desired vector file.

EXISTING VECTOR FILE STRUCTURE:
NO. SPECTRAL MEAS. = m
NO. SPATIAL MEAS. = n

CREATE SPEC. DESIGN VEC. FILE (Continued)
(Where m and n are the number
of spectral and spatial measurements
in the vector file.)

SPECTRAL FILE SET NAME =

Enter the name associated with the spectral set file that describes the desired spectral image set.

Options 1 and 2 Cont.

SPATIAL MEAS. OPTIONS:
1 - MEAN
2 - DEVIATION
3 - MEDIAN
4 - LOW
5 - HIGH
6 - RANGE
7 - FINISH
SELECTION =

Enter the number of the desired option.

Spatial Meas. Options 1-6

BOX SIZE:
ROWS =

Enter the number of rows to be included in the neighborhood surrounding each point from which to calculate the selected spatial measurement.

COLS =

Similarly, enter the number of columns to be included in the neighborhood.

SPECIFY IMAGE NOS. FROM WHICH
TO EXTRACT THE SPATIAL MEASUREMENTS.
TERMINATE LIST WITH CNTRL-Z
IMAGE NO. =

(The last line is repeated
until the user terminates
input.)

Enter the image number (spectral channel number) from which the spatial measurement is to be extracted. The list is terminated by typing "Z" while holding down the "CNTL" key and then typing a carriage return.

The spatial measurement list is
again presented and the user may
select another measurement and
another set of images from which
to calculate the measurement. This
action continues until Option 7 is
selected.

CREATE SPEC. DESIGN VEC. FILE (Continued)

Spatial Meas. Option 7

If a new file is being created, the following query is made:

VECTOR FILE NAME =	Enter the name to be assigned to the new vector file.

Otherwise, the old vector file is expanded to include the selected spatial measurements.

CREATE SPEC. TEST VEC. FILE

FRAME 9

General Description:

This routine allows the user to create a vector file from a set of spectral images or to add spatial measurements to an existing vector file. When creating a new file, a vector is formed for each pixel position within the spectral scene. The elements of these vectors consist of the corresponding pixels from each of the images in the spectral set. Spatial measurements may be added to each of the vectors when creating a new file or they may be added to an existing file. These measurements may consist of the mean, deviation, median, low, high and/or range of the values within a neighborhood about the vector position for one or more of the images in the set. The value(s) to be computed, the size of the neighborhood(s), and the image(s) from which to obtain the neighborhood pixels are all specified by the user. Each type of measurement selected can be calculated for one or more images. One measurement is obtained per type per image. For edge points, only those pixels in the neighborhood that exist in the image are used for the calculations.

For new vector files, the user is allowed to specify the accuracy with which the vector elements are to be stored. When adding to an existing file, the number of spectral and spatial measurements which make up the vectors is provided for the user's information.

Dialogue:

System	User Response
OPTIONS: 1 - CREATE NEW FILE 2 - ADD TO OLD FILE SELECTION =	Enter the number of the desired option.
	Option 1
SELECT ACCURACY DESIRED 1 - INTEGER BYTE 2 - INTEGER WORD 3 - FLOATING POINT SELECTION =	Enter the option number corresponding to the desired accuracy.
SPECTRAL FILE SET NAME =	Enter the name associated with the spectral set file that describes the desired spectral image set.

CREATE SPEC. TEST VEC. FILE (Continued)
TOTAL NUMBER OF VECTORS = n
(Where n is the number of
vectors created.)

Continue at "Options 1 & 2 Cont." below.

Option 2

VECTOR FILE NAME = — Enter the name associated with the desired vector file.

EXISTING VECTOR FILE STRUCTURE
NO. SPECTRAL MEAS. = m
NO. SPATIAL MEAS. = n
(Where m and n are the number
of spectral and spatial
measurements in the vector
file.)

SPECTRAL FILE SET NAME = — Enter the name associated with the spectral set file that describes the desired spectral image set.

Options 1 & 2 Cont.

SPATIAL MEAS. OPTIONS:
1 - MEAN
2 - DEVIATION
3 - MEDIAN
4 - LOW
5 - HIGH
6 - RANGE
7 - FINISH
SELECTION = — Enter the number of the desired option.

Spatial Meas. Options 1-6

BOX SIZE:
ROWS = — Enter the number of rows to be included in the neighborhood surrounding each point from which to calculate the selected spatial measurement.

COLS = — Similarly, enter the number of columns to be included in the neighborhood.

SPECIFY IMAGE NOS. FROM WHICH
TO EXTRACT THE SPATIAL MEASUREMENTS.
TERMINATE LIST WITH CNTRL-Z.
IMAGE NO. = — Enter the image number (spectral channel number) from which the spatial measurement

is to be extracted. The list is terminated by typing "Z" while holding down the "CNTL" key and then typing a carriage return.

The last line is repeated until the user terminates input.

The spatial measurement list is again presented and the user may select another measurement and another set of images from which to calculate the measurement. This action continues until option 7 is selected.

Spatial Meas. Option 7

If a new file is being created, the following query is made:

VECTOR FILE NAME = Enter the name to be assigned to the new vector file.

Otherwise, the old vector file is expanded to include the selected spatial measurements.

3.3.11. Frame 10 - Logic Design

This frame contains options for creating and evaluating logic. Prior to creating logic, a vector set must be specified along with a logic tree into which the logic will be placed. Initially this tree consists of only the senior node or root. As logic is created at this and subsequent nodes the tree begins to take shape.

The logic tree is specified by file name. If the file exists, it is opened and logic creation continues at the current state of the tree. If the file does not exist, a new one is created and logic creation begins at the root.

As each logic is created, a node must be specified at which the logic is to be placed. Node numbers begin at "1" with the senior node.

The capability of logic creation has been expanded to allow the dimensionality of the vectors to be expanded at any stage of the design. Any logic created up to that point will be based only upon those measurements that were available at the time.

A completed set of logic may be applied to another independent vector set for evaluation. This option requires logic tree and vector set names to be entered. It does not use the current logic tree and vector set names.

The results of applying logic to a vector set can be viewed via the creation of a thematic map. This option can only be applied to vector files where each point in the spectral scene is represented by a vector or where the row and column indices have been retained.

```
FRM 10-LOGIC DESIGN

1 - SELECT VECTOR SET
2 - SELECT LOGIC TREE
3 - CREATE FISHER LOGIC
4 - CREATE BOOLEAN LOGIC
5 - EVALUATE LOGIC
6 - CREATE THEMATIC MAP
7 - DISPLAY OPTIONS
8 - MASTER FRAME
```

SELECT VECTOR SET

FRAME 10

General Description:

This routine allows the user to select a vector set file which describes the set of vector files upon which he wishes to create logic. All vector files in the set are opened and compared with one another to insure that the dimensionality is consistent.

Dialogue:

System	User Response
VECTOR FILE SET NAME =	Enter the name associated with the vector set file that describes the desired set of vector files.

SELECT LOGIC TREE

FRAME 10

General Description:

This routine allows the user to select a logic file in which to store the created logic and the description of the resulting tree. If the file exists, it is opened and compared with the current vector file set to insure consistency with respect to the classes contained therein. All vectors are then passed through the logic that exists in the logic file. This is done to insure that the vectors have all been passed to the lowest nodes in the logic tree. Note that this would not be the case if the vector set had been previously used with a different logic file.

If the file does not exist, a new file is created and it is initialized with the classes within the current vector set.

Dialogue:

System	User Response
LOGIC FILE NAME =	Enter the name associated with the desired logic file or the name to be assigned to the logic file to be created.
If the file exists, the following is printed: VERIFYING LOGIC AND VECTOR FILES	
If the file does not exist, the following is printed: CREATING NEW LOGIC FILE	

CREATE FISHER LOGIC

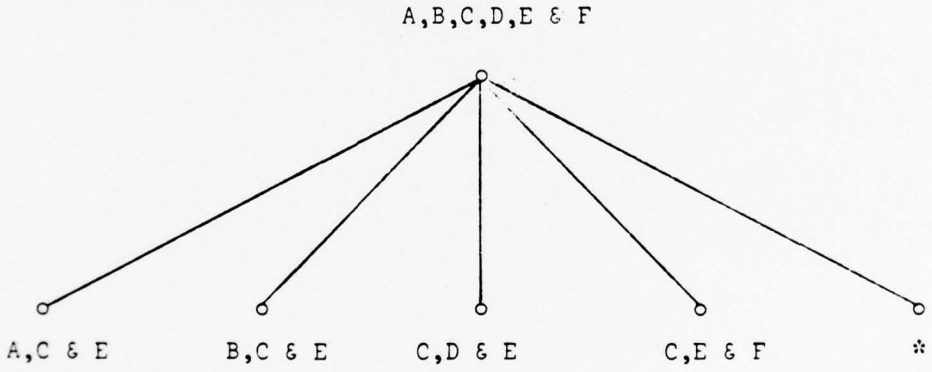
FRAME 10

General Description:

This routine creates Fisher Pairwise logic at a specified node in the current logic tree. The user must have selected a vector set and a logic tree prior to entering this routine. The node at which the logic is created must be a lowest node in the logic tree.

The mean vector and covariance matrix of each class are used to calculate the Fisher direction and threshold for each class pair. The user is given the option of using the mean vector and covariance matrix of the class data residing at the current node or using the mean vector and covariance matrix of all the class data. The user can also specify that the logic be created on a subset of the measurements and/or a subset of the classes at the selected node.

If a subset of the classes is chosen, the logic created will attempt to separate only those classes selected. The classes that are ignored will appear at each node below. For example, suppose that logic is to be created at a node in the tree where classes A, B, C, D, E and F reside. If Fisher logic is created on the subset A, B, D and F, then the following tree structure would result.



where "*" is the reject class.

The Fisher direction is computed for each class pair by summing each covariance matrix and testing for any linear dependencies. If there are dependencies, the dependent rows and columns of the matrix are removed. The matrix is inverted and a dot product is formed between the inverted matrix and the difference of the class mean vectors. At this point, if there were

any previous linear dependencies, zeroes are inserted into the appropriate column of the Fisher direction.

A threshold is also computed for each Fisher direction by forming the dot product between the Fisher direction and the sum of the mean vectors for the respective class pair. The result is the value of the threshold.

Each Fisher direction and its associated threshold are inserted into the current logic file at the current node. The node is then split into the number of classes plus one node. The extra node is a reject node which is assigned the symbol "*".

If the number of classes at the current node is greater than four, the routine will ask the user to select a minimum vote count which will be used in logic evaluation. A range will be printed on the keyboard display from which the user may select a minimum vote count. This range is determined from the minimum number of votes a class can possibly get and still have a majority in all cases and the maximum possible number of votes.

At this point, the program passes each vector at the current node through the logic. This is accomplished by calculating the dot product between the vector and each Fisher direction. If the resultant scalar is greater than or equal to the threshold, a vote is cast for the first class of this pair. If the scalar is less than the threshold, a vote is cast for the second class of this pair. After all pairs (in the user-specified subset of classes) are tested, the class with the most votes wins and the node number of this vector is changed to the node number of the winning class. The vote count of the winning class must be greater than or equal to the user-specified minimum vote count, otherwise the vector will be assigned to the reject node. If there is a tie in votes, the vector is also assigned to the reject node.

The routine returns control to the executive after all vectors at the current node in the vector set have been evaluated.

Dialogue:

System	User Response
LOGIC NODE NUMBER =	Enter the number of the node at which the logic is to be created (must be the lowest node in the tree).
DATA OPTIONS: 1 - DATA AT NODE 2 - ALL DATA SELECTION =	Enter 1 if only the vectors residing at the node are to be used for computing the Fisher logic or 2 if all the vectors in the vector set are to be used.

CREATE FISHER LOGIC (Continued)

ENTER MEAS. TO BE USED FOR CREATING LOGIC. INDIVIDUAL NOS. AND RANGES MAY BE USED. (EX: 1,3,2,7,4,8-12). A CAR. RET. ALONE SPECIFIES ALL MEAS.
MEAS. =

Enter the measurement numbers and/or ranges of measurement numbers to be used for creating the logic. If only a carriage return is entered, all measurements in the vector set will be used.

CLASSES TO OMIT FOR CREATING LOGIC =

Enter the classes to be excluded when creating the Fisher pairwise logic. All classes must be entered on one line with no embedded blanks or other separating characters.
Note: The classes omitted will appear at all nodes on the next level below the current node (except the reject node).

VOTE COUNT RANGE IS n TO m
MINIMUM VOTE COUNT =

(Where n is the lower limit of range and m is the upper limit.)

Enter the value desired for the minimum vote count. This value must be within the given range.

The vectors are passed through the logic at this time. Upon completion, control returns to the executive.

CREATE BOOLEAN LOGIC

FRAME 10

General Description:

This routine allows the user to create Boolean logic at a node in the current logic tree. Boolean logic consists of a statement constructed of arithmetic and logical operators combined with measurement and constant operands. When evaluated, this statement produces a logical true or false result. Therefore, vectors evaluated by such logic can be passed to one of two lower nodes based upon the logical result.

The operators that can be used in the construction of the statement are listed below:

Operator	Level	Description
*	3	Arithmetic multiplication
/	3	Arithmetic division
+	2	Arithmetic addition
-	2	Arithmetic subtraction
<	1	Less than
>	1	Greater than
=	1	Equal
<= or =<	1	Less than or equal
>= or =>	1	Greater than or equal
<> or ><	1	Not equal
Λ	0	Logical AND
!	0	Logical OR

There are two types of operands. The first type is a measurement operand which is designated by typing the requested measurement number preceded by the letter "M". If a measurement number greater than the dimension of the current vector set is entered, the user will be requested to enter a new statement. The first measurement is M1.

The second type of operand is a constant. This type is entered simply as the desired numerical value. Fractional values may be specified by use of a decimal point.

The operator priority level determines the order in which the operations will be performed. The operations with higher priority will be performed before operations of a lower priority. If two operations have the same priority level, the order in which they are encountered in the statement will determine the order of execution. For example, if the user enters the statement:

M1 + M2 * M3 < 100

then for a given vector, measurement two will be multiplied by measurement three before being added to measurement one. This value will then be compared to the constant, 100. If it is smaller, the vector will be assigned to the true node. If larger, a false node assignment will be made.

Parentheses are also legal characters which may be used to alter the order of operations. Operations within parentheses will be performed first. If more than one operation exists within a set of parentheses, the level of the operator's priority is used to determine the order of execution. Up to sixty-three levels of parentheses may be used in a statement.

Consider the previous statement with parentheses inserted around the first two operands:

```
(M1 + M2) * M3 < 100
```

In this case, measurement one will be added to measurement two. That quantity will be multiplied by measurement three and then compared to the constant, 100.

It may not always be possible to enter a statement entirely on one line. In this case, it may be continued on as many lines as necessary through use of the & character. For example:

```
-M1 + 10 <= (-M2) * 10/ M3 &
^(M4 + M5 <> M6 &
! M6 <250)
```

The actual statement entered in this case is:

```
-M1 + 10 <= (-M2) * 10/M3 ^(M4 + M5 <> M6!M6 < 250)
```

The previous statement also illustrates the negate feature. Measurement one is negated before being added to ten. Notice there are parentheses around the negation of measurement two. This is necessary to separate the two operators < = and -. Two operators may not appear together. Either a parenthesis or measurement variable or constant must separate operators.

After the statement has been entered, the user is given the option of accepting or rejecting the statement. This allows for a recovery from any error made in typing the statement. After the statement is accepted, the user must enter the symbols for each node.

Dialogue:

System	User Response
LOGIC NODE NUMBER =	Enter the number of the node in the logic tree at which the logic is to be created. This must be the lowest node.

CREATE BOOLEAN LOGIC (Continued)

ENTER STATEMENT. "&" AS LAST CHAR.
ALLOWS A STATEMENT TO BE CONTINUED ON
NEXT LINE. CAR. RET. WITHOUT "&"
TERMINATES STATEMENT.

Enter the desired statement as instructed.

OPTIONS:
1 - ACCEPT
2 - REJECT
3 - EXIT
SELECTION =

Enter the number of the desired option.

Option 1 continues below.
Option 2 returns to request
a new statement above. Option
3 terminates this routine and
returns control to the executive.

SYMBOLS AT CURRENT NODE ARE:

(symbols are listed here)

ENTER SYMBOLS FOR TRUE NODE (NODE NO.=n)

(where n is the number of the true node)

Enter the symbols of those classes that should evoke a true response from the logic.

ENTER SYMBOLS FOR FALSE NODE (NODE NO.=m)

(where m is the number of the false node)

Enter the symbols of those classes that should evoke a false response from the logic.

The logic is inserted into the logic tree and all vectors in the vector set at the current node are passed through the newly created logic.

EVALUATE LOGIC

FRAME 1Ø

GENERAL DESCRIPTION:

This routine allows the user to apply a given set of logic to a vector set. The logic and the vector set must be consistent with respect to dimensionality. All vectors in the set will be passed through the logic tree until they arrive at a lowest node.

Dialogue:

System	User Response
LOGIC TREE NAME =	Enter the name of the file that contains the desired logic tree.
VECTOR SET NAME =	Enter the name of the vector set file that identifies the vector files to which the logic is to be applied.

CREATE THEMATIC MAP

FRAME 10

General Description:

This routine creates a thematic map of the results of logic evaluation. A thematic map is a representation in image format of the logic classification of a set of vectors. Each class in the image is assigned a different grey value. The source of the vectors is an image or set of images where typically a vector is formed at each pixel position. Therefore, the resulting map would be a complete image where all pixels would be assigned a grey value based upon the classification of the corresponding vector. (All image points do not have to be represented by a vector if the row and column indices have been retained).

The grey value assignments for each class are made by the user. A line printer listing of the class population is provided for the users information along with the map. For each class, this listing provides the associated node number, the grey value assigned, its total population and the percentage of the total image that this population represents.

Dialogue:

System	User Response
LOGIC FILE NAME =	Enter the name of the logic file which was used to classify the vectors.
VECTOR FILE NAME =	Enter the name of the vector file (not a vector set file) from which the thematic map is to be created.
ENTER GREY VALUES (0-255) CLASS n = (Where n is a class symbol)	Enter a grey value within the range of zero to 255 to be assigned to class "n" in the thematic map.
The second line in the above request is repeated for each class in the vector file.	
The thematic map is then created and stored as an image file and the line printer listing is produced.	

3.3.12. Frame 11 - File Manipulations

This frame contains options which provide file maintenance functions. Files can be deleted or renamed and directories can be obtained.

Tape input/output options are also available. These allow image files to be transferred to and from tape. Directories are not maintained on the tape.

```
FRM 11-FILE MANIPULATIONS

 1 - DELETE FILES
 2 - RENAME FILES
 3 - SHORT DIRECTORY
 4 - LONG DIRECTORY
 5 - TAPE INPUT
 6 - TAPE OUTPUT
 7 - SKIP TAPE FILES
 8 - REWIND TAPE
 9 - DISPLAY OPTIONS
10 - MASTER FRAME
```

DELETE FILES

FRAME 11

General Description:

This routine deletes files from the specified disk directory and releases the associated disk space.

Dialogue:

System	User Response
FILE NAME WITH EXT =	Enter the name and extension associated with the file to be deleted. If several files of the same type are being deleted, the extension need only be entered with the first name. A carriage return alone causes the routine to exit.
The preceding is repeated following file deletion.	

RENAME FILES

FRAME 11

General Description:

This routine allows the user to rename files that exist in a disk file directory.

Dialogue:

System	User Response
OLD FILE NAME WITH EXT =	Enter the file name and extension associated with the file to be renamed.
NEW FILE NAME =	Enter the name to which the file is to be renamed.

SHORT DIRECTORY

and

LONG DIRECTORY

FRAME 11

General Description:

This routine allows selected directories of disk devices to be listed on the keyboard display or the line printer. The SHORT DIRECTORY option lists the file name with extension, the file size in disk blocks, and the date on which the file was created. The LONG DIRECTORY lists the number of records, the record length, and the header text in addition to the items listed by the SHORT DIRECTORY. In both cases, the entries are alphabetized first by extension and then by file name prior to listing. It should be noted that all dates after February 29, 1976 are in error by one day, relative to that entered at system start-up due to a fault in DEC's Disk Operating System.

Both options allow the user to obtain selected portions of the total device directory. All files with a particular name or all files with a particular extension may be listed alone. This is accomplished by use of an asterisk. For example, if all files with a ".IMG" extension were desired, the user would specify "*.IMG" where the asterisk indicates all.

If the listing device is the keyboard display, the directory may be split into one or more pages for viewing. The next page in the sequence is selected by entering a carriage return.

Dialogue:

System	User Response
DIRECTORY INPUT DEVICE (CR=DEFAULT DEV)=	Enter the mnemonic associated with the device whose directory is to be listed (ex. DK:).
LISTINGS CAN BE OBTAINED BY NAME OR EXTENSION. TYPE "NAME.*" OR "*.EXT" A CR LISTS ALL FILES ENTRY =	Enter the specification for the file entries to be included. A carriage return alone lists all files.
LISTING DEVICE: 1 - TEK DISPLAY 2 - LINE PRINTER SELECTION =	Enter the option number for the desired device.
Directory is listed.	

TAPE INPUT

FRAME 11

General Description:

This routine allows image files to be transferred from magnetic tape to disk. The data is expected to be stored on tape as one row per record where the last record is followed by an end of file mark. No file or tape headers are permitted. Following the transfer, the tape remains positioned after the file mark to allow the next file, if any, to be transferred.

Dialogue:

System	User
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new disk image file.
SPECIFY FILE SIZE NO. OF ROWS =	Enter the number of rows (beginning with row 1) to be transferred to disk.
NO. OF COLS =	Enter the number of columns (beginning with column 1) to be transferred to disk.

TAPE OUTPUT

FRAME 11

General Description:

This routine allows image files to be transferred from disk to magnetic tape. The data is written as one row per record beginning at the current tape position. An end of file mark is written following the last record of a file. File headers are not transferred nor are any tape headers generated. The image can be blown up by an integer factor in both row and column dimensions. Following the transfer the tape remains positioned after the last end of file mark written to allow another transfer.

Dialogue:

System	User
INPUT IMAGE NAME =	Enter the file name associated with the image to be transferred.
BLOW UP FACTOR =	Enter the integer factor necessary to attain the desired blow up.

SKIP TAPE FILES

FRAME 11

General Description:

This routine allows a magnetic tape to be moved forward past a specified number of tape files.

Dialogue:

System	User
NO. OF FILES TO SKIP =	Enter a number describing the desired number of tape files to be skipped.

REWIND TAPE

FRAME 11

General Description:

This routine causes a magnetic tape to be rewound to its load point.

Dialogue:

None

3.3.13. Frame 12 - Display Options

This frame contains image display options. Binary images can be presented on the graphics display or grey value images can be recorded on the Dicomed film recorder.

```
FRM 12-DISPLAY OPTIONS

1 - BINARY DISPLAY
2 - DICOMED HDCPY
3 - MASTER FRAME
```

BINARY DISPLAY

FRAME 12

General Description:

This routine displays a binary image (0 = black, 255 = white) on the keyboard display. Each binary zero is displayed as a blank position and each binary one is displayed as a bright dot. Depending upon the display parameters selected, all or a portion of the image may be displayed at one time. The first two parameters consist of the first row and the first column in the image at which the display is to begin. These can be any row and column existing in the image. The next parameter is the blow up factor. This determines the number of times each pixel is to be replicated in both the X and Y directions. The last parameter, element spacing, determines the spacing between dots in screen coordinates on the display. The primary purpose of this factor is to allow individual pixels to be resolved more easily. It also has the effect of a blow up factor. Therefore, the overall blow up is the product of the blow up factor and the element spacing. Accompanying the displayed image is the associated file name, the blow up factor, the element spacing, and the file header text.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the desired image.
START ROW =	Enter the row within the image at which the display is to begin.
START COL =	Enter the column within the image at which the display is to begin.
BLOW UP FACTOR =	Enter the desired blow up factor (an integer number).
ELEMENT SPACING =	The desired distance in screen coordinates between display dots.

DICOMED HDCPY

FRAME 12

General Description:

This routine allows the user to obtain hard copies of images via the Dicomed film recorder. The user can select one of three recorder resolutions, a normal or complemented copy, and a linear or log transfer function for each image printed.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the name associated with the image to be printed.
RESOLUTION OPTIONS: 1 - LOW 2 - MEDIUM 3 - HIGH SELECTION =	Enter the number of the desired option.
POLARITY OPTIONS: 1 - NORMAL 2 - COMPLEMENT SELECTION =	Enter the number of the desired option.
TRANSFER FUNCTION: 1 - LINEAR 2 - LOG SELECTION =	Enter the number of the desired option.

3.3.14. Frame 13 - Utility Functions

This frame contains various options. Included are the capabilities to exit to DOS, to maintain a log of operations, to execute a user-written program, to generate test images, to modify file header text and to list image grey values on the line printer in array format.

```
FRM 13-UTILITY FUNCTIONS

1 - DOS
2 - LOG
3 - CALL USER PROGRAM
4 - GENERATE TEST IMAGE
5 - CREATE TEST IMAGE
6 - EXAMINE HEADER TEXT
7 - LIST IMAGE GREY VALUES
8 - DISPLAY OPTIONS
9 - MASTER FRAME
```

DOS

FRAME 13

General Description:

This routine terminates execution of the Image Processing System and returns control to the DEC Disk Operating System.

Dialogue:

None

LOG

FRAME 13

General Description:

This routine when enabled maintains a record of all operations performed during a user session. This record is stored in a file and can be dumped on the line printer upon command. Interaction during graphic mode (when option frame is not displayed) operations is not recorded. The time at which each option is selected is also recorded.

Dialogue:

System	User Response
OPTIONS: 1 - START LOG 2 - DUMP LOG 3 - STOP LOG SELECTION =	Enter the number of the desired option.

Option 1

If a log file exists from a previous operation, the following is printed:

A LOG FILE CURRENTLY EXISTS DO YOU WISH TO LIST IT (Y OR N)?	Enter "Y" if the existing log is to be dumped. An "N" response will cause the file to be deleted without listing it.

LOG INITIALIZATION COMPLETE
The log routine is now active.

Option 2

The current log is listed on the line printer. No further dialogue.

Option 3

The log routine is disabled.

LOG STOPPED

CALL USER PROGRAM

FRAME 13

General Description:

This routine allows a user supplied program to be executed. A provision for more than one entry point is provided.

Dialogue:

System	User Response
USER PROGRAM NAME =	Enter the file name associated with the desired routine.
ENTRY POINT (1=1ST ENTRY PT.) =	Enter the number of the desired entry point.

GENERATE TEST IMAGE

FRAME 13

General Description:

This routine creates a test file consisting of a checkerboard pattern of grey values ranging from 0 to 255. The size of the image is 512 rows by 512 columns. Each square of constant grey value within the image is 32 rows by 32 columns. The first row of squares begins with zero density in the leftmost square, increasing by one for each square to a value of 15 in the rightmost square. Immediately below this square of grey value 15 begins the next row of squares with the value of 16. This row increases in grey value to the left to a value of 31. This sequence continues throughout the image until a grey value of 255 is reached in the lower left-hand corner of the image.

Dialogue:

System	User Response
OUTPUT IMAGE NAME =	Enter the file name to be assigned to the new image file.

CREATE TEST IMAGE

FRAME 13

General Description:

This routine allows the user to create an image by entering the value for each pixel via the keyboard. This is most useful for creating small images that can be used as test data for debugging new routines.

Dialogue:

System	User Response
NUMBER OF ROWS =	Enter the number of rows to be included in the image.
NUMBER OF COLS =	Enter the number of columns to be included in the image.
OUTPUT IMAGE NAME =	The file name to be assigned to the new image file.
PIXELS FOR ROW 1 = ROW 2 = ROW 3 = . . . ROW N	Enter the pixel values for the specified row. The values must be on one line separated by commas.

EXAMINE HEADER TEXT

FRAME 13

General Description:

This routine allows the user to examine and modify the text that is contained in any file header.

Dialogue:

System	User Response
FILE NAME WITH EXT =	Enter the name and extension associated with the desired file.
THE FOLLOWING MESSAGE APPEARS IN THE FILE HEADER: (existing header text appears here)	
ENTER NEW TEXT (CR=NO CHANGE) TEXT =	If new text is to be entered, it should be typed here. Multiple lines are allowed. The text is terminated by typing two consecutive carriage returns. If no new text is to be entered a single carriage return should be typed.

LIST IMAGE GREY VALUES

FRAME 13

General Description:

This routine allows the user to list the contents of image files on the line printer. The pixel values are listed as three digit numbers in positions relative to their locations within the image array. The user specifies the image starting row and column at which the listing is to begin and the number of rows and columns to be included in the listing. The size of the image is presented on the keyboard display to aid the user in making these selections. The user also specifies a range of grey values which are to be printed. The positions occupied by grey values outside of this range are left blank.

If the number of columns to be printed exceeds the width of the line printer, the remaining columns are listed on as many additional sheets as necessary. The starting row and column for each sheet is printed at the top of the listing. The image name, size, and header text are also listed.

Dialogue:

System	User Response
INPUT IMAGE NAME =	Enter the file name associated with the image to be listed.
IMAGE SIZE R,C = m,n STARTING R,C = (where m = no. rows and n = no. cols.)	Enter the desired starting row and column on one line separated by a comma.
NUMBER R,C TO PRINT =	Enter the number of rows and columns to be listed. Entries are on one line separated by a comma.
GREY LO,HI TO PRINT =	Enter the range of grey values to be listed.

APPENDIX A

Image Processing System

File Types

A number of files of several different file formats can be created by the Image Processing System. Each format is assigned a specific file name extension. These extensions and the type of data stored under each are listed below:

Extension	Name	Description
.FCT	Function	This file type stores statements and compiled code which result from a filter file generation.
.FLT	Filter	This file type stores a filter which is constructed under the GENERATE FILTER option.
.HAD	Hadamard	This file type is used to store the result of a Hadamard transform on an image.
.IMG	Image	This file type is used to store Images. Both grey level and binary images use this extension.
.LOG	Logic	This file type is used to store a logic tree and its associated logic.
.MC	Mean and Covariance	This file type is used to store the mean vector and covariance matrix for each class in the vector set.
.REG	Region	This file type is used to store the coordinates of the vertices of a region boundary.
.SPC	Spectral Set	This file type is used to store the names of image files which comprise a spectral set of images. Included are region

		file names, class symbols and data reduction factors all of which are used for creating design vector files.
.TMP	Temporary	This file type is used to store intermediate files generated by certain options. These files are automatically deleted upon completion of the operations which required them. In the event of a system crash or an inadvertent use of the DOS "KILL" command occurring during the program execution, one or more of these files may remain in the directory. If this occurs, the files should be deleted prior to any further processing.
.TRN	Transfer Function	This file type is used to store the transform functions generated by the options: THRESHOLD, ELEMENT CHANGE, and ARBITRARY FUNCTION.
.VCS	Vector Set	This file type is used to store the names of vector files which comprise a vector set. Logic creation operations are performed only on vector sets.
.VEC	Vector	This file type is used to store the measurement vectors formed from one spectral set.
.WGT	Weight	This file type is used to store the weight arrays entered via the weighted smooth options.

APPENDIX B

Image Processing System

Error Messages

The following list of messages is used by the system to report error conditions which may occur due to such things as an incorrect user entry, an attempt to perform an illegal operation, a specification of a nonexistent file, a hardware error, etc. The messages range from very specific to general and are grouped into two categories. The first category reports conditions from which a recovery can be made and processing can continue. These are called recoverable errors. The second group are fatal errors from which no recovery can be made. In the latter case, the executive regains control following the error report.

In both groups, the error messages are assigned a unique number and are prefaced with "E0" for recoverable errors and "E1" for fatal errors. This numbering scheme is helpful in searching the following lists for a detailed explanation of the error.

Recoverable Errors

E0.0. SPECIFIED FILE IS NONEXISTENT
- RETYPE

The file name that has just been entered was not found on the specified device. A recovery can be made by entering a different name, or possibly the same name, with a different device or unit number.

E0.1. FILE HAS INCORRECT DATA TYPE
- RETYPE

Information stored in the header of the specified file indicates that it is not of the correct type (see Appendix A for file types). Its file name extension may have been changed via the DOS utility program "PIP." In any case, the file cannot be used and another name should be entered.

E0.2. INCORRECT FILE SPECIF. FORMAT
- RETYPE

The file specification (device, unit, file name and extension) was not entered in the prescribed format. Re-enter it in the correct format.

E0.3. INPUT STRING SYNTAX ERROR
- RETYPE

The syntax of the character string just entered is not correct. Check the appropriate option in the user's manual (Section 3) for the correct syntax.

E0.4. ILLEGAL FRAME NUMBER
- INPUT IGNORED

The specified frame does not exist. No action was taken.

E0.5. ILLEGAL OPTION NUMBER
- INPUT IGNORED

The selected option does not exist in the current list of options. No action was taken.

E0.6. INPUT STRING TOO LONG
- RETYPE

The input character string that has just been entered is too long for the input buffer. Retype it in a reduced format or on several lines if allowed.

E0.7. PREVIOUS PREMATURE FILE CLOSE
- TYPE CO TO CONTINUE

The specified file was created under another option that was terminated prior to the closing of the file. Therefore, the data in the file is in an unknown state. Type "CO" if the file is to be used in spite of its uncertainty. If "CO" is not typed, the execution of the option is terminated.

E0.8. REFERENCED PICTURE ELEMENT
NONEXISTENT - RETYPE

The previous entry referenced a picture element that did not exist in the specified image file. Enter a corrected specification.

E0.9. DUPLICATE FILE NAME
- RETYPE

The name entered for the file that is being created is already in use. Enter another name.

E0.10. INCORRECT PARAMETER VALUE
- RETYPE

The value of the parameter just entered is not within the range of expected values. Enter another value.

E0.11. A NONEXISTENT PICTURE ELEMENT
WAS REFERENCED

This error does not require any action on the user's part. It is simply a warning message that operations were attempted outside the range of the image dimensions.

E0.12. INCORRECT NUMBER OF ENTRIES
- RETYPE

The number of entries (on one line) that were typed is not the same as the number requested. Enter the correct number of entries.

E0.13. INCORRECT FILE FORMAT
- RETYPE

The specified file is not of the correct format (linked, contiguous). Select another file.

E0.14. ILLEGAL FILE NAME
- RETYPE

The specified name contains characters which are not allowed in a file name. Enter another name.

E0.15. SPECIFIED FILE IS NONEXISTENT
- INPUT IGNORED

The file specified for deletion did not exist. Therefore, no action was taken.

E0.16. ILLEGAL DEVICE
- RETYPE

The specified device cannot be used for the selected operation or the device does not exist in the hardware configuration.

E0.17. INCORRECT
- RETYPE

The previous input was not as expected. Enter it in the correct format.

E0.18. TOO MANY PARENTHESES
- RETYPE

The specified statement exceeds the limit of 63 levels of parentheses.

E0.19. ILLEGAL CHAR.
- RETYPE

A character in the last entry is illegal in the current context. Retype the string without the offending character.

E0.20. PARENTHESES DO NOT BALANCE
- RETYPE

The statement just entered contains a different number of left and right parentheses. Retype the corrected statement.

E0.21. ILLEGAL OPERATOR
- RETYPE

The statement just entered contains an operator that is not allowed. Retype the corrected statement.

E0.22. OPERAND MISSING
- RETYPE

The statement just entered does not have a sufficient number of operands for the operators used. Retype the corrected statement.

E0.23. ARITHMETIC OPERAND EXPECTED
- RETYPE

An operator in the statement requires an arithmetic operand but is given a logical operand. Retype the corrected statement.

E0.24. LOGICAL OPERAND EXPECTED
- RETYPE

An operator in the statement requires a logical operand but is given an arithmetic operand. Retype the corrected statement.

E0.25. OPERATOR MISSING
- RETYPE

The statement just entered does not have a sufficient number of operators for the operands specified. Retype the corrected statement.

E0.26. ARITH. STATEMENT INCOMPLETE
- RETYPE

The equal sign or the symbol to the left of the equal sign were not present in the arithmetic statement. Retype the corrected statement.

E0.27. LOGICAL ARGUMENT INCOMPLETE
- RETYPE

The expression entered does not yield an expected logical result. Retype the corrected statement.

E0.28. ILLEGAL OR INCOMP. STATEMENT
- RETYPE

The statement just entered does not follow the format of any legal statement type. Retype the corrected statement.

E0.29. INSUFFICIENT NO. OF POINTS
- INPUT IGNORED

The number of data points entered was not sufficient for the current operation. No action was taken.

E0.30. FLOATING PT. OVER/UNDER FLOW
- RETYPE

The number just entered has exceeded the range of values accepted by the floating point processor. The absolute value of the number must be made smaller.

E0.31. ILLEGAL SYMBOL
- RETYPE

The class symbol just entered either does not exist in the current data set or cannot be used for the current operation.

E0.32. ILLEGAL LIMITS
- RETYPE

The limits specified for the current operation are not within an acceptable range of values. Enter a new set of limits.

E0.33. ILLEGAL MEASUREMENT
- RETYPE

The measurement specified exceeds the dimensionality of the current vector set. Use a different measurement number.

E0.34. DID NOT USE ALL CLASS SYMBOLS
- INPUT IGNORED

All of the class symbols at the current node in the logic tree were not assigned to sub-nodes. The assignment must be done again.

Fatal Errors

E1.0. HARDWARE ERROR ON TRANSFER
- OPERATION ABORTED

A hardware error occurred on a data transfer between memory and a peripheral. Consult maintenance personnel.

E1.1. CORE SPACE EXHAUSTED
- OPERATION ABORTED

The memory available is not sufficient to perform the requested operation. If a neighborhood operation was involved, try the operation again with a smaller neighborhood specification.

E1.2. FILE DIMENSION ERROR
- OPERATION ABORTED

The dimensions of the specified file(s) are not acceptable to the current option. If combining two images, insure that they are of the same dimensions.

E1.3. DUPLICATE FILE NAME
- OPERATION ABORTED

An attempt was made to create a file under a name that was already in use. The error occurred at a point in the processing where a recovery was not possible. Check the directory for temporary files. If any exist, delete them.

E1.4. ILLEGAL DEVICE
- OPERATION ABORTED

A device specified for the current operation is not acceptable or is nonexistent. Circumstances do not permit a recovery. If performing operations using spectral or vector sets, check the names listed within these files for correctness.

E1.5. DEVICE FULL
- OPERATION ABORTED

The output device specified for the current operation is full or does not have sufficient space for the required output.

E1.6. TEMPORARY FILE ERROR
- OPERATION ABORTED

An operation on a temporary file resulted in an error. Request a directory of temporary files and delete all that are listed. If the delete option fails, use the DOS utility routine "PIP" to unlock the offending file.

E1.7. SYSTEM TABLE OVERFLOW
- OPERATION ABORTED

This error should not occur for the current set of options. User-added software, however, could put greater demands on the system such as a larger number of "open" files required than is allowed. Consult the system manager to expand the system table in question.

E1.8. BAD UID OR DIRECTORY FULL
- OPERATION ABORTED

Either the user ID has not been entered onto the device being accessed or the directory for the device is full. For disk devices, a full directory implies that there is no more space left on the disk. Try listing a directory of the device. If this fails, then the UID does not exist on the device. Use the DOS utility routine "PIP" to enter the desired UID onto the device. If the directory is obtained, then use PIP to verify that the device is full.

E1.9. DISPLAY COORDINATES ILLEGAL
- OPERATION ABORTED

An attempt was made to plot a coordinate on the graphics display that exceeded its range of existing coordinate positions. This error is not expected to occur. Consult the system manager if it does.

E1.10. NONEXISTENT RECORD REFERENCE
- OPERATION ABORTED

A reference was made to a record that does not exist in a file specified for the current operation. Examine the parameters entered for the operation to insure correctness.

E1.11. DOS CORE SPACE EXHAUSTED
- OPERATION ABORTED

The DOS monitor has been requested to perform an operation for which it does not have sufficient memory available. Consult the system manager.

E1.12. PROTECTION CODE VIOLATION
- OPERATION ABORTED

An operation was attempted on a file which is prohibited by the file's protection code. Consult the DOS utility routine "PIP" to change the protection code of the file in question.

E1.13. FILE OPEN
- OPERATION ABORTED

This error should not occur. User-supplied software may have violated the system by opening a file under DOS and then attempting to open the same file through the image processing system.

E1.14. LENGTH OR NO. OF RECORDS ZERO
- OPERATION ABORTED

One or both of the dimensions of the current file are zero. No operations can be performed on it.

E1.15. IMAGE DIMENSION INSUFFICIENT
- OPERATION ABORTED

A dimension of an image file currently being accessed is not sufficient for the specified operation. Circumstances do not permit a recovery.

E1.16. ZERO ENTRIES
- OPERATION ABORTED

A list of entries was requested and none were entered.

E1.17. ILLEGAL FILE NAME
- OPERATION ABORTED

A file name is constructed with a character that is not acceptable to DOS. Check the names in a spectral or vector set file if such a file is being accessed.

E1.18. A REQUIRED FILE IS NONEXIST.
- OPERATION ABORTED

A file that is required for the current operation does not exist. Check the names in a spectral or vector set file if such a file is being accessed.

E1.19. INCORRECT FILE FORMAT
- OPERATION ABORTED

The format of a file currently being accessed is not as expected. Investigate all files involved in the current operation to insure that they are consistent with one another to the extent required by the current operation. Also check if the files are contiguous (except for the automatic log file.)

E1.20. FILE HAS INCORRECT DATA TYPE
- OPERATION ABORTED

A file that has been specified for the current operation contains data that is not as indicated by its file name extension (it may have been renamed by PIP).

E1.21. RECORD SEQUENCY ERROR
- OPERATION ABORTED

This error is not expected to occur. It could result from a user routine that opens a file for "write" access only and then attempts to access the data in a random manner.

E1.22. LOG FILE CREATE ERROR
- OPERATION ABORTED

An error occurred in creating the log file "LOGFIL.IPS". This error is not expected. If it occurs, it could be due to a user routine that has

already opened a file under the same name.

E1.23. LOG FILE OPEN ERROR
- OPERATION ABORTED

An attempt to dump or delete a previously existing log file failed. This is most probably due to a prior system crash. Use the DOS utility routine "PIP" to unlock the file and then try again.

E1.24. FAILURE ON "OPEN" OPERATION
- OPERATION ABORTED

An error has occurred on attempting to open a dataset. Insure that all devices specified for the operation exist and that any new software is not attempting to perform an illegal operation.

E1.25. INCORRECT NO. DEP. VARIABLES
- OPERATION ABORTED

A function has been specified for creating a filter file that has more dependent variables than specified or allowed (two max.).

E1.26. LOG ARG. < OR = TO Ø
- OPERATION ABORTED

An attempt has been made to calculate the log of a number that is less than or equal to zero.

E1.27. NEIGHBOR OPERATIONS ILLEGAL
- OPERATION ABORTED

Neighborhood references have been made in a statement (ex. for filter creation) for an operation that does not recognize or allow them.

Note: Neighborhood references are allowed for image combinations operations found in planned future software additions.

E1.28. UNEXPECTED END OF FILE
- OPERATION ABORTED

An end-of-file was encountered prior to completing the current operation. This could occur for magnetic tape as well as for disk files.

E1.29. ILLEGAL LOGIC FILE OPERATION
- OPERATION ABORTED

An attempt was made to operate on a logic tree file in a manner which is not allowed. User-added software may be responsible. If not, consult the system manager.

E1.30. CLASS SYMBOLS INCONSISTENT
- OPERATION ABORTED

The files that are currently being used for logic creations are not consistent with respect to the class symbols that they reference. Check to insure that the names have been entered correctly.

E1.31. NODE DOES NOT EXIST
- OPERATION ABORTED

A node has been referenced that does not exist in the current logic tree.

E1.32. *NODE NOT LOWEST NODE*
- OPERATION ABORTED

An attempt has been made to create logic at a node to which logic has already been assigned. Logic can only be created at terminal nodes.

E1.33. SYMBOLS ALREADY EXIST AT NODE
- OPERATION ABORTED

This error is due to a corrupted logic tree file. This could result from a previous logic creation operation that was interrupted prior to completing its assigned task.

E1.34. ILLEGAL REGION
- OPERATION ABORTED

This error occurs when a region is referenced whose interior cannot be determined due to a questionable boundary.

E1.35. MULTIPLE SYMBOLS AT A LOW NODE
- OPERATION ABORTED

The option selected demands that only one class reside at each terminal node (i.e., logic must be completed). At least one terminal node was found to have more than one class.

E1.36. NO CLASS SYMBOLS IN VEC FILE
- OPERATION ABORTED

For the current operation, each vector in the vector set must have a class symbol assigned to it.

METRIC SYSTEM

BASE UNITS:

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

SUPPLEMENTARY UNITS:

plane angle	radian	rad	...
solid angle	steradian	sr	...

DERIVED UNITS:

Acceleration	metre per second squared	...	m/s
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s
angular velocity	radian per second	...	rad/s
area	square metre	...	m
density	kilogram per cubic metre	...	kg/m
electric capacitance	farad	F	A·s/V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V·s/A
electric potential difference	volt	V	W/A
electric resistance	ohm		V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	kg·m/s
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m
luminance	candela per square metre	...	cd/m
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg·K
stress	pascal	Pa	N/m
thermal conductivity	watt per metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m/s
voltage	volt	V	W/A
volume	cubic metre	...	m
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

SI PREFIXES:

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto*	h
10 = 10^{1}	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi*	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

* To be avoided where possible.

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